Stabilization of Expansive Soils Using Waste Plastic Fibers for Pavement Subgrades

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Abstract - Expansive soils pose significant challenges in flexible pavement construction due to their high shrink–swell potential and low bearing strength. To overcome these issues sustainably, this study investigates the stabilization of expansive soil using waste plastic fibers derived from discarded PET bottles. Four fiber contents—0.5%, 1.0%, 1.5%, and 2.0% by dry weight of soil—were examined to evaluate their influence on subgrade behaviour. Laboratory tests, including the Standard Proctor Test, California Bearing Ratio (CBR), and Unconfined Compressive Strength (UCS), were performed to determine changes in Maximum Dry Density (MDD), Optimum Moisture Content (OMC), and strength characteristics. Results revealed that the inclusion of plastic fibers significantly enhanced the soil's mechanical properties. Both CBR and UCS values increased with fiber addition up to an optimum level, after which a minor reduction was observed. The strength improvement was mainly due to the random distribution of fibers, which provided effective interlocking, restricted crack development, and improved load transfer within the soil matrix. Overall, the use of PET waste fibers offers a sustainable, low-cost, and eco-friendly approach to stabilizing expansive soils, contributing to improved subgrade performance and environmental conservation.

Keywords: Expansive soil, PET fiber, Subgrade stabilization, Sustainable materials, CBR, UCS.

1.INTRODUCTION

Soil forms the essential foundation for all highway and pavement structures, making its evaluation and improvement critical before construction. Clayey soils, commonly encountered in many regions, are highly compressible and exhibit significant shrink–swell behaviour, becoming hard when dry and weak when wet. These characteristics make them unsuitable for supporting pavements unless properly stabilized. Soil stabilization is therefore employed to improve engineering properties such as shear strength, volume stability, and load-bearing capacity, ultimately enhancing subgrade performance while reducing construction costs.

Sustainable stabilization techniques have gained importance due to growing environmental concerns. Among them, the use of waste materials—particularly plastic bottle strips derived from polyethylene terephthalate (PET)—offers a promising solution. PET plastics are durable, non-biodegradable, and abundantly available as waste, making their reuse both environmentally and economically beneficial. Incorporating stone dust, a byproduct of aggregate production, further enhances soil properties while minimizing waste disposal issues.

Stabilization is especially valuable for problematic soils like expansive clay, peat, or silt, which require improved strength and moisture resistance for safe construction. By integrating waste plastic fibers and stone dust, this study seeks to develop a cost-effective, eco-friendly, and high-performance stabilization method suitable for flexible pavement subgrades.

2. OBJECTIVES OF THE STUDY

1. To evaluate the compaction characteristics of Black Cotton Soil (BCS), BCS + stone dust, and BCS + plastic fiber mixes using the Standard Proctor Test to determine Optimum Moisture Content (OMC) and Maximum Dry Density (MDD).
2. To assess the improvement in strength characteristics of the stabilized soil mixes through California Bearing Ratio (CBR) tests for determining subgrade load-bearing capacity.
3. To examine the changes in shear strength and cohesive behaviour of the soil using the Unconfined Compressive Strength (UCS) test for different percentages of plastic fibers.
4. To analyze the effect of stone dust and plastic fiber addition on the plasticity behaviour of Black Cotton Soil using Atterberg Limits tests (Liquid Limit, Plastic Limit, and Plasticity Index).
5. To identify the optimum mix proportion of BCS, stone dust, and plastic fibers that provides maximum improvement in engineering properties—compaction, strength, plasticity, and suitability for flexible pavement subgrades.

3.MATERIAL AND METHODOLOGY

Stone Dust (Sand Dust)

Stone dust is a byproduct obtained from crushing stones during aggregate production. It is generally light grey in color and consists of fine angular particles with good mineral composition. Due to its granular nature, stone dust improves the gradation and packing of soil mixtures, enhancing compaction and strength. It possesses stable physical characteristics such as specific gravity, bulk density, and fineness, making it suitable as a partial replacement material in soil stabilization. Its mineral constituents—primarily silica, alumina, and iron oxides—contribute to improved interparticle bonding and reduced void ratios when mixed with expansive soils.

Plastic Bottle Fibers (PET Fibers)

Waste plastic bottle fibers are derived from recycled polyethylene terephthalate (PET). The fibers are typically cut into small flaky or irregular shapes. PET is a non-biodegradable polymer known for its high tensile strength, chemical resistance, and durability. When used as an additive in soil, these fibers act as reinforcement by providing interlocking and bridging effects. This enhances shear strength, reduces crack propagation, and improves the ductility and load-bearing performance of the stabilized soil. Being lightweight and chemically inert, PET fibers do not react with soil minerals but significantly enhance mechanical properties through physical reinforcement.

Table 1 Physical Properties

Property	Sand Dust	Plastic Bottle (2 mm size)
Specific Gravity	2.65	1.38
Bulk Density (g/cc)	1.62	0.85
Fineness Modulus	2.45	-
Moisture Content (%)	0.5	0.0
Grain Shape	Angular	Flaky/Irregular
Color	Light Grey	Transparent to Blue

Table 2 Chemical Properties

Constituent	Sand Dust (%)	Plastic Bottle (%)
SiO_2	85.0	~0 (non-mineral)
Al_2O_3	7.0	~0
Fe_2O_3	3.5	~0
CaO	2.0	~0
MgO	1.0	~0
Others	1.5	100% PET ($C_{10}H_8O_4$ polymer)

3.1 METHODOLOGY

This study investigates the stabilization of Black Cotton Soil (BCS) using stone dust and waste plastic fibers (PET and LDPE). The methodology follows a systematic sequence beginning with material collection, characterization, sample preparation, and laboratory testing performed as per relevant Indian Standard (IS) codes. The experimental program was designed to evaluate the improvement in engineering behaviour of expansive soil through the incorporation of plastic fibers at varying proportions (0.5%, 1.0%, 1.5%, and 2.0%) along with a constant 10% stone dust replacement.

3.1 Materials and Sample Preparation

Black cotton soil was collected from the study area and classified based on index and engineering properties. Waste PET bottle strips (2 mm size) and LDPE plastic fragments were sourced from local waste collection centres, cleaned, shredded, and prepared for use as stabilizing agents. Stone dust, obtained from a crusher plant, was used as a partial replacement material. All materials were oven-dried, pulverized, and sieved according to IS 2720 requirements. The soil–stone dust–plastic mixes were prepared by thoroughly blending 90% BCS, 10% stone dust, and the designated plastic percentages on a dry weight basis.

3.2 Test Procedures

3.2.1 Sieve Analysis

Particle size distribution was determined as per IS 2720 (Part 4). Oven-dried samples were passed through a standard set of IS sieves to classify the soil and identify gradation characteristics.

3.2.2 Specific Gravity

Specific gravity of soil was determined using a pycnometer following IS 2720 (Part 3). The ratio of the mass of soil solids to an equal volume of water at standard conditions was computed.

3.2.3 Atterberg Limits

Liquid limit and plastic limit were determined as per IS 2720 (Part 5) using the Casagrande apparatus and thread-rolling method. These limits were used to classify soil plasticity and evaluate the impact of additives.

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3.2.4 Free Swell Index

Free swell index was conducted following IS 2720 (Part 40) using distilled water and kerosene to quantify the soil's expansive behaviour.

3.2.5 Standard Proctor Compaction Test

Compaction characteristics (OMC and MDD) were evaluated using the Standard Proctor Test as per IS 2720 (Part 7). Soil mixes were compacted in three layers using a 2.6 kg rammer. Dry density values were plotted against moisture content to obtain OMC and MDD.

3.2.6 California Bearing Ratio (CBR)

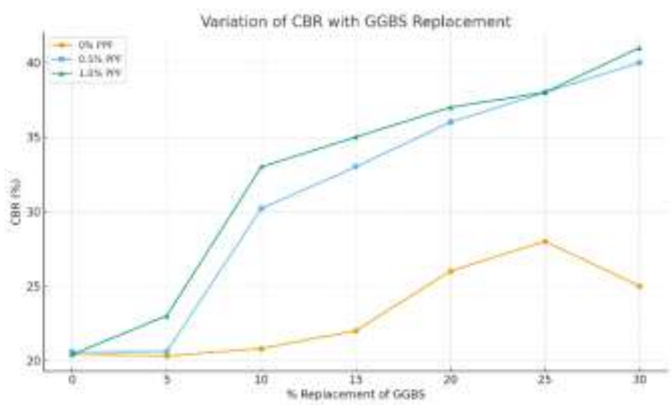
CBR tests on remoulded samples were performed in accordance with IS 2720 (Part 16). Penetration load was recorded at 2.5 mm and 5.0 mm to compute the CBR value.

3.2.7 Vane Shear Test

Undrained shear strength of cohesive soil was measured as per IS 2720 (Part 30) using a laboratory vane shear apparatus. Maximum torque at failure was used to compute shear strength.

4.Result and discussion:

4.1 CBR



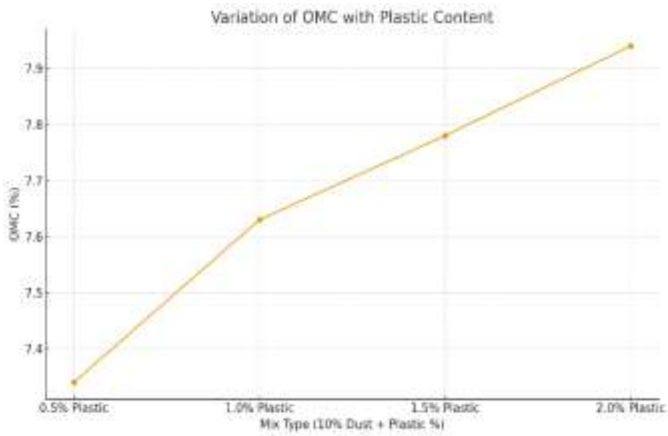


Figure 2: Variation of Optimum Moisture Content (OMC) with Plastic Content in Soil–Stone Dust–Plastic Mix

Specific Gravity of Soil

The specific gravity results present table 1 indicate minimal variation across all mixes. The natural black cotton soil (BCS) exhibited a specific gravity of 2.65. Incorporating 10% stone dust with 0.5% plastic resulted in a value of 2.64, while mixes with 2% plastic recorded 2.65. Overall, the specific gravity ranged narrowly between 2.64 and 2.66, demonstrating that the addition of stone dust and bottle plastic does not significantly influence the density of soil solids. This consistency suggests that both materials act primarily as stabilizers without altering the intrinsic unit weight of the soil particles.

Liquid Limit

The liquid limit results reveal a decreasing trend in adjusted moisture content with increasing bottle plastic content. The control sample (0% plastic) exhibited the highest liquid limit (43.84%–51.85%), reflecting the high swelling potential and lower shear strength of untreated BCS at elevated moisture levels. The introduction of 0.5% and 1.0% plastic reduced the liquid limit to ranges of 41.41%–50.76% and 41.12%–50.39%, respectively, due to displacement of clay fines and reduced water absorption. A notable decrease was observed at 1.5% plastic (33.79%–55.5%), indicating the most effective reduction in plasticity. At 2.0% plastic, the liquid limit increased marginally (36.93%–44.31%), suggesting that excess plastic disrupts uniformity and slightly increases water retention. Overall, plastic fiber inclusion improves moisture resistance and reduces the tendency for moisture-induced deformation.

Plastic Limit

Plastic limit values showed a progressive reduction with increasing plastic content up to 1.5%, followed by a slight increase at 2.0%. The untreated soil displayed the highest plastic limit of 27.77%, reflecting its strong affinity for water. The addition of 0.5% and 1% plastic reduced the plastic limit to 26.68% and 25.0%, respectively, due to reduced clay-water interaction. The lowest value (22.8%) occurred at 1.5% plastic, indicating improved workability and minimized plasticity. At 2.0% plastic, the slight increase to 25.71% is attributed to uneven water distribution caused by excess plastic fibers. These results confirm that controlled plastic addition effectively reduces water demand and enhances soil handling characteristics.

Swell Index

The free swell index values confirmed significant improvement in swelling behaviour with the inclusion of stone dust and plastic. Natural BCS exhibited a high swell index of 120%, classifying it as highly expansive. The addition of 10% stone dust reduced the swell index to 100%. Further addition of plastic produced substantial reductions: 90% at 0.5% plastic, 80% at 1% plastic, and the lowest value of 70% at 1.5% plastic. At 2% plastic, the swell index increased slightly to 80%. The results indicate that 1.5% plastic provides the most effective reduction in volumetric swelling, after which the benefit diminishes.

Standard Proctor Test

Compaction data in Tables 4.6 and 4.7 show that both MDD and OMC improved with the inclusion of stone dust and bottle plastic. Natural BCS displayed an MDD of 1.92 g/cc at an OMC of 8.20%. With 10% stone dust and 0.5% plastic, MDD increased to 1.98 g/cc at 7.34% OMC. The mix with 1% plastic achieved an MDD of 2.06 g/cc at 7.63% OMC. The highest compaction was obtained at 2% plastic, where MDD reached 2.14 g/cc with an OMC of 7.94%. These results confirm that plastic fibers and stone dust enhance compaction efficiency by improving particle packing and reducing void spaces.

Dry Density – Results and Discussion

Dry density values show a consistent increase with plastic content up to 1.5%, beyond which a slight reduction occurs. For the 10% stone dust + 0.5% plastic mix, dry density ranged from 1.89 to 1.98 g/ccm, demonstrating improved packing due to angular stone dust particles. At 1% plastic, γd increased to 1.97–2.06 g/ccm, indicating an optimal balance between soil particles and plastic fibers, which enhanced interlocking. The highest dry densities (2.01–2.10 g/ccm) were recorded at 1.5% plastic, showing effective densification. At 2% plastic, γd values ranged from 2.05–2.14 g/ccm, but marginal reductions were noted due to excessive plastic fibers disrupting soil structure. This trend confirms that moderate plastic content enhances compaction, while excessive plastic leads to inefficient packing.

California Bearing Ratio (CBR)

CBR results indicate that plastic inclusion significantly improves the load-bearing capacity of BCS up to an optimum level. With 0.5% plastic, CBR values were 8.0% (2.5 mm) and 7.6% (5.0 mm), representing a notable enhancement over untreated soil. The highest CBR was obtained at 1.0% plastic, reaching 8.5% and 8.0%, attributed to better interlock and particle reinforcement. Beyond this point, CBR values decreased: 7.2% and 6.9% at 1.5% plastic, and 6.5% and 6.3% at 2% plastic. The decline suggests that excessive plastic introduces voids and weak zones, reducing penetration resistance. Overall, moderate plastic content improves subgrade strength, while excessive amounts adversely affect bonding and stiffness.

Vane Shear Test

The vane shear results (Table 4.10) show a progressive increase in shear strength with increasing plastic content up to 1.5%. Natural BCS recorded a shear strength of 0.120 kg/cm². With 10% stone dust and 0.5% plastic, strength increased to 0.135 kg/cm², and peaked at 0.147 kg/cm² for 1.5% plastic, indicating enhanced cohesion due to fiber reinforcement. At 2% plastic, strength decreased slightly to 0.140 kg/cm², suggesting that excessive plastic reduces bonding efficiency and disrupts soil structure. The results clearly demonstrate that controlled plastic addition enhances shear strength, with 1.5% plastic providing maximum improvement.

5.Conclusions

This study evaluated the effects of incorporating bottle plastic (2 mm size) and 10% dust stone on the engineering properties of black cotton soil, focusing on compaction characteristics, Atterberg limits, and California Bearing Ratio (CBR). The results clearly demonstrate that plastic inclusion influences soil behavior significantly, with improvements observed up to an optimum content of 1.5%.

The dry density increased consistently with plastic addition, reaching its highest value at 1.5%, where improved compaction and particle packing were evident. Beyond this level, a slight reduction in dry density occurred, indicating that excess plastic interrupts the soil matrix and reduces compaction efficiency due to the inert and non-cohesive nature of plastic particles. This highlights the necessity of maintaining an optimal plastic percentage to ensure effective stabilization.

Similarly, plastic limit and liquid limit values decreased as plastic content increased, indicating a reduction in soil plasticity and moisture-holding capacity. This improvement enhances the workability of the soil. However, at 2.0% plastic, a rise in plastic limit was recorded, emphasizing the adverse effects of higher plastic content on moisture distribution and soil structure.

The CBR results further validated the positive influence of plastic on soil strength, with the highest values observed at 1.0% plastic content. This improvement is attributed to enhanced inter-particle bonding and reduced deformation under load. However, as plastic content increased to 1.5% and 2.0%, CBR values declined, demonstrating that excessive plastic leads to void formation and reduced load-bearing capacity.

Overall, the findings confirm that plastic waste can be effectively utilized as a sustainable additive in soil stabilization, especially at moderate levels ranging from 1.0% to 1.5%. The study enhances the understanding of soil–plastic interactions and provides valuable guidance for subgrade improvement and road construction applications. Future studies should focus on evaluating long-term durability and environmental impacts to ensure sustainable implementation in civil engineering practices.

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