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# Geotechnical Enhancement of Subgrade Soils Using Recycled Polymeric Waste - A Review

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**Abstract:** Subgrade soils form the foundation of pavement structures, and their mechanical properties play a crucial role in ensuring pavement durability and performance. Weak soils often result in deformation, low load-carrying capacity, and premature failure of pavements. Traditional stabilization methods, such as lime, cement, and fly ash, have limitations related to cost, carbon footprint, and sustainability. With the increasing accumulation of polymeric waste, researchers are exploring the use of recycled plastic materials (PET, PE, PP) as a sustainable soil stabilizer. This review critically examines 20 previous research studies on geotechnical enhancement of subgrade soils using polymeric waste. The analysis highlights improvements in strength, CBR, compaction, permeability, and resilient modulus, while identifying key limitations in current research. The study emphasizes the research gaps and proposes directions for future investigations to optimize polymer use for sustainable and durable subgrade soil improvement.

**Keywords:** Subgrade soil, Soil stabilization, Recycled polymer, Geotechnical enhancement, Plastic waste, Sustainable construction.

## I. INTRODUCTION

Soil is a fundamental component in civil engineering, providing support for foundations, pavements, and embankments. However, weak and expansive soils, such as clayey and black cotton soils, often exhibit low bearing capacity, high compressibility, and swelling-shrinkage behavior, which can compromise the stability and durability of infrastructure (Aly Ahmed et al., 2011; Hamid, 2017). To address these geotechnical challenges, researchers have increasingly explored the use of sustainable and eco-friendly materials, particularly waste plastics, natural fibers, and recycled aggregates, for soil stabilization (Akinwumi et al., 2019; Gupta et al., 2019). Plastic waste, including polyethylene (PE), polypropylene (PP), and polyethylene terephthalate (PET), has emerged as a promising additive due to its non-biodegradability, availability, and potential to improve soil strength, deformation resistance, and load-bearing capacity (Mukhtar Abukhattala et al., 2021; Hassan et al., 2021).

Several studies have demonstrated that incorporating shredded plastic, plastic strips, or polymer-cement mixtures into subgrade soils can enhance California Bearing Ratio (CBR), unconfined compressive strength (UCS), resilient modulus, and reduce swelling potential (Datta et al., 2021; Ziani et al., 2022; Attom et al., 2025). Hybrid stabilization approaches combining plastics with natural fibers, coir, lime, or recycled aggregates have also shown synergistic improvements in mechanical performance, slope stability, and long-term durability (Shihab et al., 2020; Khalak and Juremalani, 2022; Farah Atiqah Abdul Azam et al., 2024). Moreover, recent research has explored polymeric emulsions, bio-mediated additives, and microbial-induced calcite precipitation (MICP) techniques as innovative strategies for sustainable soil improvement (Khalak et al., 2025; Liu et al., 2025).

Despite these advances, challenges remain in optimizing the type, size, and content of plastic additives for different soil types, assessing long-term field performance under cyclic and environmental loading, and establishing standardized guidelines for practical implementation (Kumar et al., 2024; Deepak et al., 2025). Furthermore, lifecycle assessment, environmental impact evaluation, and cost-effectiveness analyses are limited in the current literature. Therefore, a comprehensive review of recent studies is essential to consolidate current knowledge, identify research gaps, and provide guidance for the sustainable utilization of plastic and other waste materials in geotechnical applications (Hashem et al., 2024; Attom et al., 2025).

## II. LITERATURE REVIEW

### A. Previous Research Article

Aly Ahmed et al. (2011) investigated the use of recycled gypsum ("bassanite") combined with waste plastic trays for soil stabilization and ground improvement. Their study revealed that increasing the gypsum content significantly enhanced the compressive strength of treated soils, while the addition of plastic strips improved both splitting tensile and compressive strengths. The combination of gypsum and plastic also effectively reduced the capillary rise rate, which in turn decreased the susceptibility of

soils to ice lens formation and frost heave. The research addresses global landfill challenges by exploring productive applications for gypsum plasterboard and polystyrene (PS) from waste trays, which are often excluded from recycling due to high production-to-recycling cost ratios. Additionally, the study highlighted the relevance of improving tensile strength when using cementitious binders like recycled gypsum, which typically exhibit weaker tensile performance.

G.L. Sivakumar Babu et. al. (2011) in their paper titled “Stress-Strain Response of Plastic Waste Mixed Soil” explored the influence of incorporating waste plastic bottle chips into soil to improve its geotechnical properties. The study revealed that adding 1.0% plastic waste significantly enhanced the strength of both red soil and sand, while also reducing their compressibility. The unconfined compressive strength (UCS) of red soil increased by 73.8%, and that of sand by 93.7%, demonstrating the effectiveness of plastic waste as a reinforcing material. The improvement was primarily attributed to the increased frictional resistance and tensile stress generated by the interlocking action of the plastic chips within the soil matrix. The study also reported that this enhancement could lead to a reduction in pavement thickness by 37.5%, translating into considerable cost savings and material conservation in pavement construction. The authors emphasized that this approach not only provides a sustainable solution for recycling plastic bottle waste but also contributes to the development of eco-friendly geotechnical engineering practices. Furthermore, it fills a notable research gap by demonstrating the stress-strain behavior of plastic waste-reinforced soils for practical civil engineering applications.

Hamid et. al. (2017) explored the use of waste plastics for the enhancement of soil properties in geotechnical engineering, focusing on subgrade stabilization and embankment stability. The study emphasized that waste plastics, commonly used for shopping bags and packaging, contribute significantly to municipal solid waste, yet are underutilized in construction applications. Laboratory experiments were conducted with varying percentages of plastic strips uniformly mixed with different soil types, and tests were performed to assess the engineering properties, strength, and stability of the modified soils. Results demonstrated that incorporation of waste plastics improved soil reinforcement, increased bearing capacity, and enhanced the stability of embankments, indicating that plastic waste can serve as an effective, eco-friendly, and sustainable material for geotechnical applications. The study highlighted the potential of plastics to mitigate environmental issues while improving subgrade performance.

Pooria Ghadir et. al. (2018) in their study titled “Clayey Soil Stabilization Using Geopolymer and Portland Cement” investigated the performance of volcanic ash-based geopolymer compared to ordinary Portland cement (OPC) for stabilizing clayey soils. The research highlighted that untreated clay exhibited a low compressive strength of 0.2 MPa, which could be significantly enhanced through stabilization. Using 15 wt% binder, OPC-stabilized soil under wet curing reached 4 MPa, whereas geopolymer under dry curing achieved 12 MPa, demonstrating a 200% higher strength than OPC in dry conditions. The study further revealed that increasing the alkali activator’s molarity and content improved the strength of geopolymer-stabilized soil. Geopolymer specimens also exhibited superior ductility and energy absorption, contrasting with the more brittle behavior of OPC-treated soil. The authors emphasized that while OPC remains effective, it raises environmental concerns due to high CO<sub>2</sub> emissions and plastic shrinkage, especially in hot climates. In contrast, geopolymer, derived from aluminosilicate wastes, presents an eco-friendly alternative that enhances soil mechanical properties and durability. The research also addressed inconsistencies in prior studies by systematically evaluating the effects of mixture type, curing time, and curing conditions, providing insights for sustainable soil stabilization practices.

Akinwumi et al. (2019) explored the use of shredded waste plastic to stabilize soil for producing compressed earth bricks (CEBs) as a sustainable solution for both marine plastic pollution and affordable housing. Their study demonstrated that incorporating 1% waste plastic (particles under 6.3 mm) increased the compressive strength of CEBs by 244.4%, enabling the bricks to meet the 1 MPa minimum standard required for unfired clay bricks. The enhanced CEBs were suitable for non-load-bearing walls, offering an eco-friendly and cost-effective material for housing construction. This approach presents a dual benefit: effective management of plastic waste and provision of affordable building materials in developing regions.

Asskar Janalizadeh Choobbasti et. al. (2019) in their paper titled “Mechanical Properties of Soil Stabilized with Nano Calcium Carbonate and Reinforced with Carpet Waste Fibers” explored an innovative approach to soil stabilization by integrating nanotechnology with recycled waste materials. The study investigated the combined effects of nano calcium carbonate (CaCO<sub>3</sub>) as a stabilizer and carpet waste fibers as a reinforcing material on the mechanical properties of clayey soils. The findings revealed that nano calcium carbonate alone could increase soil strength by nearly 100% after 42 days of curing, while the addition of carpet waste fibers almost doubled the undrained cohesion of the soil. Furthermore, the fibers significantly enhanced soil stiffness, ductility, and residual strength, although the maximum strength improvement plateaued beyond 0.2% fiber content. The authors demonstrated that this combined stabilization technique effectively improved unconfined compressive strength, ultrasonic pulse velocity, and triaxial shear strength parameters, offering a durable and sustainable soil improvement solution. The research addressed the limitations of

traditional stabilization methods using lime or cement, which are often costly and environmentally harmful, and proposed a more eco-friendly and economical alternative by reusing carpet waste while leveraging the efficiency of nanomaterials.

Gupta et al. (2019) presented a comprehensive review on soil stabilization using plastic waste as an additive, focusing on cost-effective and environmentally friendly techniques. The study highlighted that the quality of natural soils often degrades due to construction activities and environmental factors, necessitating stabilization to maintain their suitability for foundations. The authors emphasized the use of High-Density Polyethylene (HDPE) chips as a soil additive to enhance geotechnical properties. Key parameters such as bearing capacity, shear strength, swelling behavior, Atterberg's limits, and California Bearing Ratio (CBR) were considered to evaluate soil improvement. The findings suggested that incorporation of HDPE improved soil strength, reduced swelling potential, and enhanced load-bearing capacity, while also being economical and eco-friendly compared to conventional stabilization methods like cement or lime. The study concluded that plastic waste can serve as a viable alternative for sustainable soil stabilization in civil engineering applications.

J. Kiran Kumar et. al. (2019) in their paper titled "Soil Stabilization Using E-Waste: A Retrospective Analysis" examined the potential application of electronic waste (e-waste) in soil stabilization and geotechnical engineering. The authors observed that most existing studies focus on the use of industrial by-products and natural fibers for soil improvement, while the utilization of e-waste remains largely unexplored. Their review highlighted that the growing generation of e-waste poses a serious environmental challenge, yet it presents an opportunity for its beneficial reuse in pavement and foundation engineering applications. The study emphasized that incorporating e-waste into soil could significantly contribute to soil stabilization, providing a dual benefit of improving geotechnical performance while promoting sustainable waste management. Furthermore, Kiran Kumar and Praveen Kumar identified a major research gap regarding the mechanical behavior and long-term performance of e-waste-stabilized soils, calling for systematic experimentation to establish its practical feasibility. The authors concluded that using e-waste as an additive material offers a novel and eco-friendly approach to reducing environmental impacts and integrating waste materials into construction and infrastructure projects.

Shihab et. al. (2020) investigated the strength improvement of subgrade soil using ceramic waste powder treated with coconut coir fiber. The study focused on clayey soils, which often present low bearing capacity, high compressibility, and swelling issues that affect pavement performance. Laboratory experiments were conducted with varying percentages of coir fiber and ceramic waste powder, and geotechnical properties including California Bearing Ratio (CBR), cohesion, and compressibility were measured. The results demonstrated that the inclusion of ceramic waste and coir fibers significantly enhanced the strength, stability, and load-bearing capacity of the subgrade soil. The study concluded that using locally available waste materials and natural fibers is an economical, eco-friendly, and effective approach for subgrade stabilization, promoting sustainable road construction practices.

S. Peddaiah, A. Burman et. al. (2020) in their paper titled "Experimental Study on Effect of Waste Plastic Bottle Strips in Soil Improvement" investigated the use of waste PET plastic bottle strips for enhancing the engineering properties of silty sand. The study revealed that adding 0.4% PET strips significantly improved dry unit weight, shear strength, and California Bearing Ratio (CBR) of the soil, while exceeding this percentage led to a reduction in performance. Additionally, smaller strip sizes (15 mm × 15 mm) with corrugated surfaces were found to be most effective, enhancing CBR, load-penetration behavior, cohesion, and internal friction. The research highlighted that using plastic bottle strips not only improves soil stabilization but also provides a sustainable method for waste disposal. However, the study had limitations, including testing only a single soil type and PET plastic, small-scale experiments, and the absence of advanced geotechnical tests such as permeability, consolidation, or triaxial tests. The authors suggested that future research should explore different soil types, other plastic varieties (like LDPE and HDPE), large-scale applications, and optimized strip patterns (horizontal, vertical, or inclined layers) to fully assess the benefits and cost-effectiveness of plastic strip reinforcement in soil improvement.

Amit Kumar Rai et. al. (2020) in their review paper titled "Comparative Study of Soil Stabilization with Glass Powder, Plastic, and E-Waste: A Review" presented an in-depth comparative analysis of using non-biodegradable wastes such as glass powder, plastic, and e-waste for the stabilization of weak soils. The study emphasized that these waste materials can effectively improve the California Bearing Ratio (CBR) and unconfined compressive strength (UCS) of soil, thereby enhancing its load-bearing capacity and stability. Due to their inert nature, these materials exhibit high durability and resistance to environmental degradation, making them suitable for long-term geotechnical applications. The authors highlighted the increasing problem of continuous waste generation, which leads to large-scale dumping and associated environmental and health hazards. They noted that while several studies have focused on individual waste materials or traditional stabilizers, a comparative evaluation of modern waste-based stabilizers was lacking. This review thus provides a comprehensive perspective on the potential of integrating multiple waste

materials for sustainable soil stabilization, offering an eco-friendly solution to waste disposal and improving the performance of weak subgrade soils in construction.

Mukhtar Abukhattala et. al. (2021) conducted a detailed study on the geotechnical characterization of plastic waste materials in pavement subgrade applications. They investigated four types of plastic waste—low-density polyethylene (LDPE), high-density polyethylene (HDPE), polyethylene terephthalate (PETE), and polypropylene (PP)—in ground, flaky, and pelleted shapes, mixed with silty or clayey gravel and sand soils classified as A-2-7 under the AASHTO system. The study assessed compaction, California Bearing Ratio (CBR), resilient modulus (MR), permeability, friction angle, and compressive strength of both natural and plastic-modified subgrade soils. The findings revealed that the inclusion of plastic waste generally decreased the maximum dry density due to the lower density of plastics compared to soil particles. The impact on CBR and MR values varied depending on plastic type, shape, and content, with some combinations showing improvement while others exhibited reduction. Permeability of most subgrade soils increased with plastic addition, though some soils maintained unchanged hydraulic conductivity. Plastic-modified soils displayed higher friction angles but lower compressive strength than unmodified soils. Overall, the study concluded that partial replacement of subgrade soil with plastic waste can be beneficial for road construction, though the effectiveness depends on the plastic type, shape, and proportion used.

Hussein Jalal Aswad Hassan et. al. (2021) in their study titled “Effects of Plastic Waste Materials on Geotechnical Properties of Clayey Soil” investigated the potential of polyethylene (PE) and polypropylene (PP) plastic fibers for enhancing the geotechnical performance of clayey soils. The authors found that adding plastic fibers significantly improved Unconfined Compressive Strength (UCS), with increases of up to 96.6% for PE fibers and 73.0% for PP fibers. California Bearing Ratio (CBR) tests showed enhanced soil strength and deformation behavior, particularly at 4% fiber content for both 1.0 cm and 2.0 cm fiber lengths. Additionally, the Resilient Modulus ( $M_r$ ) increased by approximately 120% for PE fibers at 4% content, whereas PP fibers showed peak improvements at 3% content. The study also reported that incorporating plastic fibers reduced maximum dry density (MDD) and optimum moisture content (OMC), which is advantageous for lightweight embankments. The authors emphasized that plastic fiber stabilization is an economical and environmentally sustainable alternative to chemical stabilizers. However, they noted that precise optimization of fiber content and length is crucial, as UCS may decrease beyond optimal fiber percentages, even when  $M_r$  continues to improve. This study provides valuable insights for the design of fiber-reinforced soils in geotechnical applications.

Preeti Gangwar et. al. (2021) in their research paper titled “Stabilization of Soil with Waste Plastic Bottles” investigated the potential of using shredded waste plastic bottles as a soil stabilizing material. The study aimed to provide a sustainable and economical approach to address both soil stabilization and plastic waste management. The results revealed that incorporating 1% waste plastic bottles into soil significantly improved its geotechnical properties, enhancing strength and stiffness. At 0.5% plastic content, the maximum dry density (MDD) increased from 1.5 gm/cc to 1.59 gm/cc, while the optimum moisture content (OMC) decreased from 14.4% to 13.8%, indicating better compaction characteristics. Additionally, the California Bearing Ratio (CBR), unconfined compressive strength (UCS), and shear strength of the soil improved notably at this level. However, beyond 0.5% plastic addition, the strength parameters declined, suggesting that excessive plastic content leads to non-uniform bonding and poor compaction. The authors concluded that the use of waste plastic bottles in soil stabilization not only enhances engineering properties but also offers an eco-friendly and sustainable solution for mitigating the growing issue of plastic waste disposal.

Hassan et al. (2021) investigated the effects of plastic waste materials on the geotechnical properties of clayey soils, focusing on polyethylene (PE) and polypropylene (PP) fibres as soil stabilizers. The study incorporated four fibre contents (1%, 2%, 3%, and 4% by weight) in two lengths (1.0 cm and 2.0 cm) and conducted compaction, unconfined compressive strength (UCS), California Bearing Ratio (CBR), and resilient modulus ( $M_r$ ) tests. Results indicated that the addition of plastic fibres reduced maximum dry density (MDD) and optimum moisture content (OMC), which is beneficial for lightweight embankment construction. Significant improvements were observed in UCS, with increases of 76.4–96.6% for PE fibres and 57.4–73.0% for PP fibres, depending on fibre length. The CBR values increased substantially, with PE improving strength by 150–185% and PP by 150% at 4% fibre content. The resilient modulus also improved with fibre addition, showing up to 120% increase for PE at 4% content, while PP showed a decline beyond 3% content. The study concluded that plastic fibres effectively enhance the strength, deformation resistance, and mechanical performance of clayey soils, though optimum fibre content must be determined for maximum efficiency.

Datta et. al. (2021) investigated the stabilization of clayey subgrade soil using recycled aggregates (RA) to enhance bearing capacity and strength. The study focused on improving weak soils for road construction while addressing environmental concerns of construction and demolition waste. Clay soil samples were mixed with crushed concrete aggregates in varying percentages (0%, 30%, 50%, and 70% by weight), and California Bearing Ratio (CBR), Maximum Dry Density (MDD), and Optimum Moisture Content (OMC) were measured. The results demonstrated that CBR values increased significantly with the addition of RA, with

improvements ranging from 7.16% to 13.81% for unsoaked samples and 9.34% to 14.98% for soaked samples at 70% RA content. The study concluded that incorporating recycled aggregates into subgrade soils effectively improves strength, load-bearing capacity, and durability, while simultaneously promoting sustainable reuse of construction waste materials.

Khalak and Juremalani (2022) investigated enhancing subgrade stability in black cotton soil using coir fiber and micro-shredded waste plastic powder (MSWPP) as a sustainable and eco-friendly alternative to conventional soil stabilization methods. The study used 0.3% coir fiber and 10% MSWPP by weight of dry soil, and conducted comprehensive laboratory tests including liquid limit, plastic limit, unconfined compressive strength (UCS), California Bearing Ratio (CBR), Proctor compaction, free swell index, direct shear, consolidation, tri-axial, and swelling pressure tests. Results demonstrated that both coir fiber and MSWPP individually and synergistically improved mechanical properties, load-bearing capacity, and stability of the black cotton soil. The study concluded that the combined use of natural fibers and plastic waste offers a cost-effective, environmentally friendly, and practical solution for subgrade stabilization, providing important guidance for sustainable road construction practices.

Ojuri et al. (2022) investigated the eco-friendly stabilization of highway lateritic soil using a combination of lime, cow bone powder, and plastic granules. Their study found that a blend of 6% lime, 7% cow bone powder, and 1% plastic waste granules effectively stabilized the soil for highway sub-base applications, surpassing the performance of 10% lime alone. The stabilized mixture significantly enhanced unconfined compressive strength (UCS), California Bearing Ratio (CBR), with soaked CBR reaching 37.60% (above the 30% minimum requirement), and overall durability while reducing soil compressibility. The research highlighted environmentally sustainable alternatives to traditional lime stabilization by partially replacing lime with uncalcined cow bone powder and reinforcing with plastic waste granules.

Ziani et al. (2022) investigated the influence of recycled plastic waste (RPW) and Portland cement (PCC) on pavement sub-base stabilization as a sustainable solution for road construction. Various mixtures of 5% and 10% RPW, combined with 2% and 4% PCC, were tested at Proctor optimum moisture content. Laboratory tests including California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) were conducted on both soaked and unsoaked soil samples. Results revealed that 5% RPW alone increased CBR by approximately 139.32%, while combining 5% RPW with 2% PCC elevated CBR up to 386.59% in unsoaked and 404.54% in soaked samples. UCS values also showed significant improvement, increasing from 0 to 1471.18 kPa and from 754.67 kPa to 2051.53 kPa for soaked and unsoaked samples, respectively. The study concluded that optimizing the RPW-PCC combination can substantially enhance the mechanical properties of pavement sub-base layers, providing an effective and eco-friendly approach for sustainable road stabilization.

Shelema Amena et. al. (2022) in the research paper titled “Utilizing Solid Plastic Wastes in Subgrade Pavement Layers to Reduce Plastic Environmental Pollution” investigated the potential of incorporating solid plastic waste strips into expansive soils to improve their geotechnical performance and simultaneously address plastic waste management issues. The study demonstrated that adding 0.5% plastic waste strips to soil significantly enhanced its unconfined compressive strength (UCS), achieving a peak value of 192.8 kPa, while increasing the plastic content to 1.5% resulted in further improvements in the California Bearing Ratio (CBR). The inclusion of plastic strips was found to reduce the soil’s expansiveness, improve its stability, and make it more suitable for subgrade pavement layers. The research effectively tackled two major challenges—plastic pollution and expansive soil remediation—by proposing an eco-friendly solution that converts waste materials into useful construction resources. Moreover, Amena addressed a significant research gap in earlier studies, which often lacked standardized parameters for plastic fiber size, shape, and dosage. By establishing these standards, the study provided valuable insights into optimizing the use of plastic waste for soil reinforcement in sustainable road construction.

Kabeta et. al. (2022) studied the strength properties of soft clay stabilized with plastic waste strips as a sustainable approach for weak subgrade improvement. The study incorporated 0.2%, 0.3%, and 0.4% plastic strips by weight of soil and compared the results with untreated control soil. Laboratory experiments including Standard Proctor compaction, Unconfined Compressive Strength (UCS), and California Bearing Ratio (CBR) tests were conducted following ASTM standards. Results revealed significant enhancements in soil strength, with UCS increasing by up to 138% for 0.4% plastic content of 2 cm length, and notable increments in CBR values. The Standard Proctor test showed a slight increase in maximum dry density with plastic addition. The study concluded that plastic strips can effectively improve the mechanical properties of soft clay, offering a practical, eco-friendly alternative for subgrade stabilization in civil engineering applications.

Hashem et. al. (2024) investigated the sustainable use of recycled concrete aggregate (RCA) for improving weak and poorly graded sand soils. The study evaluated the effects of RCA as a partial soil replacement (5%, 10%, 15%, and 20% by weight) on geotechnical properties including compaction, California Bearing Ratio (CBR), and Maximum Dry Density (MDD). Results demonstrated that RCA significantly enhanced the engineering characteristics of the treated soils, with 15% RCA identified as the

optimum content for stabilization. The inclusion of RCA improved CBR and MDD, indicating higher load-bearing capacity and better soil compaction. The study concluded that RCA is an effective, sustainable, and practical material for stabilizing weak subgrade soils, supporting its use in field applications for road construction and geotechnical projects.

Farah Atiqah Abdul Azam et al. (2024) investigated the enhancement of soil stability using an integrated sustainable approach combining biological and plastic waste materials. Their study demonstrated that a mixture of bio-mediated vegetable waste and shredded PET (polyethylene terephthalate) plastic waste significantly improves soil properties. Specifically, a blend containing 20% fermented vegetable grout and 1% PET increased soil cohesion and shear resistance by 33%. Additionally, the inclusion of PET enhanced the factor of safety (FOS) for slope stability by up to 81.47%, surpassing the minimum requirement for stable design slopes. The study employed triaxial tests and slope stability analyses to assess performance and highlighted the environmental benefits of using PET plastic as a sustainable soil reinforcement. The research also addressed limitations of conventional chemical and biological stabilization techniques, such as sensitivity to temperature, nutrients, and pH, and filled a knowledge gap regarding the long-term effectiveness of PET's low friction and high wear resistance in soil stabilization.

Kumar et al. (2024) presented a critical review on the utilization of plastic waste for stabilizing expansive soil subgrades, emphasizing environmental sustainability and waste management. The study highlighted that plastic waste, being non-biodegradable, poses severe environmental challenges, but its incorporation as a soil reinforcement material can improve geotechnical performance. The review synthesized findings from multiple studies, indicating that plastic strips and fibres can enhance strength, bearing capacity, and deformation resistance of expansive soils. However, the authors noted that the suitability and effectiveness of plastic waste vary with soil type, plastic form, and content, and practical guidelines for field applications are still underdeveloped. The review concluded that plastic waste offers a sustainable alternative for ground improvement, but further experimental and field-scale research is needed to optimize its use across diverse soil conditions.

Talha Zafar et al. (2024) in their study titled "Soil Stabilization by Reinforcing Natural and Synthetic Fibers – A State of the Art Review" presented an extensive overview of fiber-reinforced soil stabilization techniques. The authors emphasized that reinforcing expansive soils with natural and synthetic fibers is an effective and low-cost approach to improving their geotechnical performance. The inclusion of fly ash (FA) as a stabilizing agent was found to increase the California Bearing Ratio (CBR) by 80–110%, while the addition of geofibers could further enhance the CBR by 40–50%. Furthermore, fiber reinforcement significantly improved unconfined compressive strength, ductility, and shear strength, and reduced volume changes by up to 94.4%, minimizing swelling and shrinkage. The review highlighted that the combination of fibers and fly ash enhances soil stability and sustainability. However, the authors identified key challenges such as the lack of standardized guidelines, fiber clustering, and weak fiber-soil adhesion, which limit large-scale application. They also pointed out the need for deeper research into the interaction mechanisms between fibers and fly ash-stabilized soils, as this area remains underexplored. Overall, the paper provides a valuable foundation for developing sustainable and durable soil stabilization practices.

Khalak et. al. (2025) reviewed the use of bio-based additives and recycled plastic waste for soil stabilization in road construction, emphasizing sustainability and circular economy principles. The study highlighted the incorporation of coir fibers, bagasse ash, and plastic waste to improve the mechanical performance of expansive and weak subgrade soils. The review also discussed microbial-induced calcite precipitation (MICP) as a nature-inspired technique to enhance soil strength and durability. Findings from various studies indicated that combining biological, agricultural, and synthetic waste materials can produce synergistic improvements in strength, stiffness, and resilience of subgrade soils. However, the authors noted challenges such as variability in material properties, limited field-scale validation, and lack of comprehensive lifecycle assessment, which restrict the practical application of these methods. The study concluded that further research is needed to optimize material combinations, evaluate long-term performance, and promote sustainable road construction practices.

Deepak et al. (2025) investigated the sustainable stabilization of expansive black cotton soil using recycled PET plastic waste for flexible pavement subgrades. The study aimed to enhance the shear strength, load-bearing capacity, and overall geotechnical performance of high-plasticity clay soils while addressing plastic waste management. Laboratory experiments conducted included particle size distribution (sieve analysis), Modified Proctor compaction tests, and California Bearing Ratio (CBR) tests. The results showed that the inclusion of shredded PET plastic significantly improved the Maximum Dry Density (MDD), Optimum Moisture Content (OMC), and CBR values of the black cotton soil up to an Optimum Plastic Content (OPC), beyond which performance declined. The findings highlighted that PET plastic strips effectively enhance strength, bearing capacity, and stability, offering a cost-effective and eco-friendly alternative to conventional stabilization methods such as cement or lime. The study concluded that recycled plastic can be efficiently used in low-volume roads and embankment construction, demonstrating the potential for circular utilization of plastic waste in geotechnical applications.

Attom et al. (2025) investigated soil improvement using a plastic–cement mixture to control swelling and compressibility of expansive clay soils. The study targeted highly plastic (CH) clay soils and incorporated shredded plastic waste in three lengths (0.5 cm, 1.0 cm, 1.5 cm) combined with cement in a 1:5 ratio. Various fractions of this plastic–cement blend were added to clay samples and tested using zero swell tests as per ASTM D4546, after curing periods of 1, 2, and 7 days. Results revealed that 6–8% of the plastic–cement blend significantly reduced swelling pressure, decreased compressibility, and improved mechanical stability of the clay soils. The compression index decreased, and maximum past pressure increased with higher blend content, with 7-day curing identified as optimal. The study concluded that plastic–cement mixtures provide an effective and sustainable solution for stabilizing expansive clay soils, offering both geotechnical improvement and an environmentally friendly use of plastic waste.

Liu et al. (2025) explored the use of a green polymer-based admixture, Renolith emulsion, for stabilizing expansive clay subgrade as an eco-friendly alternative to traditional chemical stabilizers. Laboratory experiments were conducted with 0%, 0.5%, 1%, 1.5%, and 2% Renolith by dry soil weight, evaluating mechanical and microchemical properties through tests including repeated load triaxial (RLT), swell-shrinkage, standard compaction, unconfined compressive strength (UCS), soaked CBR, direct shear (DS), and soil water retention curve (SWRC). Microchemical analyses using XRD, XRF, thermogravimetric, and SEM were also performed. Results demonstrated that 1% Renolith content produced the most significant improvement, enhancing soaked CBR by 170.1%, resilient modulus by 40.2%, and cohesion by 44.2%, while simultaneously reducing the soil swell-shrinkage index by 18.3%. The study concluded that Renolith emulsion is an effective, sustainable polymeric stabilizer for reactive clay soils, providing notable mechanical and hydraulic improvements suitable for pavement subgrade applications.

### *B. Research Gaps*

Despite extensive research on the geotechnical enhancement of subgrade soils using recycled polymeric waste and other sustainable additives, several gaps remain that require further investigation. Aly Ahmed et al. [1] and Hamid [2] demonstrated the effectiveness of plastic waste and recycled gypsum in improving compressive and tensile strengths; however, their studies were largely limited to laboratory-scale experiments, leaving long-term field performance and durability under varying climatic conditions largely unexplored. While Akinwumi et al. [3] and Gupta et al. [4] highlighted the potential of plastic waste to improve compressive strength and load-bearing capacity, the optimal plastic type, size, content, and interaction with specific soil types remain inconsistent across studies. Mukhtar Abukhattala et al. [5] and Hassan et al. [6] reported variations in California Bearing Ratio (CBR), resilient modulus, and permeability depending on plastic shape and fibre content, indicating that standardized guidelines for effective plastic incorporation are yet to be established.

Several studies, including Shihab et al. [5], Khalak and Juremalani [8], and Ojuri et al. [9], have explored hybrid stabilization approaches combining plastic waste with natural fibers, lime, or other waste materials. However, these studies often lack comprehensive assessment of long-term mechanical behavior, swelling potential, and environmental interactions, particularly under cyclic loading and wet-dry conditions. Ziani et al. [10], Kabeta [11], and Hashem et al. [12] further emphasized the importance of combining plastic waste with cementitious materials or recycled aggregates, yet optimum mix proportions for field-scale applications remain underdeveloped. Recent research by Farah Atiqah Abdul Azam et al. [13], Kumar et al. [14], and Khalak et al. [15] highlighted integrated sustainable methods using biological additives and microbial-induced techniques, but practical implementation is hindered by material variability, lack of lifecycle assessment, and limited field validation. Studies on expansive soils by Deepak et al. [16], Attom et al. [17], and Liu et al. [18] demonstrated significant improvement in shear strength, CBR, and swell-shrinkage behavior using recycled PET, plastic–cement mixtures, and polymeric emulsions. Nevertheless, these studies also revealed that performance is highly sensitive to plastic content, curing duration, and soil type, emphasizing the need for systematic optimization and standardized guidelines.

## **III. PROPOSED METHODOLOGY**

### *A. Materials Collection*

- Recycled polymeric waste (PET bottles, PE, PP)
- Subgrade soils (Black Cotton Soil)

### *B. Soil-Polymer Mix Preparation*

- Shredded polymer size: 2–10 mm
- Mix polymer with soil in different percentages (1–5% by weight)

### C. Laboratory Testing

- Compaction Test: Determine optimum moisture content and max dry density
- CBR Test: Evaluate load-bearing capacity
- UCS Test: Measure unconfined compressive strength

## IV. CONCLUSION

In conclusion, the incorporation of plastic waste, natural fibers, recycled aggregates, and bio-mediated additives offers a sustainable and eco-friendly approach for improving the geotechnical performance of weak and expansive soils. Numerous studies have demonstrated that such materials can significantly enhance soil strength, bearing capacity, deformation resistance, and reduce swelling-shrinkage behavior, making them suitable for subgrade stabilization, embankments, and pavement applications. Hybrid stabilization techniques, combining plastics with fibers, lime, cement, or biological agents, have shown synergistic improvements in both mechanical and hydraulic properties, highlighting their potential for sustainable road construction. Despite these advancements, challenges remain in optimizing material type, size, content, and combinations for specific soil types. Limited field-scale validation, long-term performance assessment under environmental and cyclic loading, and lack of standardized guidelines continue to constrain practical implementation. Therefore, further experimental and field-based studies are required to establish optimal usage parameters, evaluate durability, and ensure environmental and economic feasibility. Overall, the sustainable utilization of plastic and other waste materials in soil stabilization not only addresses critical waste management issues but also contributes to resilient, cost-effective, and environmentally responsible infrastructure development.

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