A REVIEW ON THE UTILIZATION OF PLASTIC WASTE FOR SUSTAINABLE FLEXIBLE PAVEMENT IN BANGLADESH

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ABSTRACT

Plastic waste stands as a significant global concern, which has far-reaching effects. The rapid growth of plastic consumption and the resulting waste generation have led to serious environmental challenges, particularly in developing countries like Bangladesh where recycling systems are inefficient. Utilizing plastic waste in pavement construction presents a sustainable solution that not only enhances the performance of transportation infrastructure but also minimizes environmental pollution. The utilization of plastic waste in pavement construction has been the subject of extensive research in recent decades. This review discusses the potential of incorporating plastic waste into bituminous pavements, focusing on how it supports the goals of sustainable transportation infrastructure. The paper categorizes commonly used plastic types and highlights two primary incorporation techniques- dry and wet processes, evaluating their influence on pavement performance indicators such as strength, stability, durability, and resistance to moisture and rutting. Findings from multiple studies indicate that use of plastic has been found to improve the strength, durability, and load-carrying capacity of roads. Roads made with plastic waste perform better against cracking, rutting, and moisture damage. Many studies also suggest that these pavements last longer and require less maintenance. However, challenges remain in standardizing material proportions, ensuring field performance, and addressing long-term environmental impacts. The review aims to serve as a comprehensive resource for engineers, policymakers, and researchers in understanding how using plastic waste in pavements can be a practical, cost-effective, and sustainable alternative option for modern transportation.

Keywords: *plastic waste; sustainable pavement; modified bitumen.*

1. INTRODUCTION

A well-developed and durable road network is fundamental to the socio-economic growth of any country. Bangladesh has an extensive national road network of over 22,476 kilometers under the Roads and Highways Department (RHD), with the majority of roads having flexible pavements. According to the Maintenance and Rehabilitation Needs Report 2023–2024, 6.16% of these roads were classified as Poor, while 2.49% and 1.84% were rated as Bad and Very Bad, respectively, and require a total of 9479.75 crore Taka for maintenance (Roads and Highways Department, 2023). Additionally, there are 249,814.67 km of upazila, union, and village-level roads under the Local Government Engineering Department (LGED), with 161,322.35 paved roads (*Road & Market Database*, n.d.). However, on this large scale of the road network, many flexible pavements across the country continue to suffer from premature deterioration. Poor construction quality, heavy traffic loads, and harsh weather have made pavement distress a common issue. In Bangladesh, flexible pavements are failing significantly earlier than design life; while they are designed to last 20 years, their actual service life typically spans only 4.5 to 5 years. (Hamim & Hoque, 2019). In Rajshahi, about 23% of paved roads were in failure condition, with common issues including cracks, potholes, and rutting, often due to poor materials and drainage (Hasan & Sobhan, 2020). In Dhaka, Pavement Condition Ratings (PCR) for major roads range from 58 to 92 out of 100, indicating that while some roads are in fair condition, more than half require regular maintenance or overlays (Hasan et al., 2024).

At the same time, Bangladesh is experiencing a significant increase in plastic consumption and waste plastic waste generation over the years. From 3.0 kg in 2005 to 9.0 kg in 2020, Bangladesh's annual per capita urban plastic use tripled. As of right now, the cumulative generation of plastic waste in Bangladesh is around 977,000 tons of plastic per year, which is 10% of the total volume of waste (The World Bank, 2024). Managing this large amount of plastic waste is very difficult for a developing country like Bangladesh. According to The World Bank, (2021) report, 48% of plastic waste is disposed of in landfills, 37% is recycled, 12% ends up in rivers and khals, and 3% is deposited in city corporations' unserved areas and drains. Only a small number of waste collection locations are covered by secondary transfer stations, which restricts the amount of plastic recovered from municipal waste before it is dumped in landfills. An estimated 24,032–36,047 tons of plastic waste are disposed of annually at 1,212 hot spots around rivers and khals, all of which are connected to the river system. This mismanagement leads to plastic pollution, which severely affects both the environment and public health in Bangladesh. It contaminates air, water, and soil, disrupts ecosystems, and contributes to flooding and agricultural damage. Microplastics and toxic additives like BPA and phthalates enter the food chain and are linked to serious health issues such as hormonal imbalance, infertility, and cancer (Hossain et al., 2021). Without proper management, the harmful effects of plastic waste will continue to increase.

By converging these 2 major problems, utilizing plastic waste in flexible pavement construction can be a promising solution. Incorporating plastic waste into flexible pavement construction not only enhances pavement performance but also provides an effective waste management strategy. Modified bitumen using plastic polymers has been found to improve key physical, rheological & engineering properties. It makes pavements more resilient to deformation and cracking under high traffic loads and unfavorable weather conditions, extending their lifespan. (Ma et al., 2021; Vishnu & Singh, 2021; Xu et al., 2022). At the same time, this approach helps reduce the volume of plastic waste and reduces its negative environmental and health impacts. Given the dual benefits of improving road quality and addressing plastic waste challenges, this technique presents a practical, low-cost, and eco-friendly solution for Bangladesh.

The objective of this paper is to explore the potential of utilizing plastic waste in flexible pavement construction as a sustainable solution to improve pavement performance in Bangladesh. It aims to review existing research, highlight benefits, and assess its applicability in the local context.

2. TYPES OF PLASTIC WASTE IN BANGLADESH

Plastic waste is a major environmental issue in Bangladesh, with various types and sources contributing to the problem. The most common types of plastic waste are **low-density polyethylene (LDPE), polyethylene terephthalate (PET), and high-density polyethylene (HDPE), Polypropylene (PP), Polystyrene (PS) and Polyvinyl Chloride (PVC).**

They primarily originate from packaging, bottles, and consumer goods. Key sources include households, industry, commercial, and transport sectors. Bangladesh's LDPE waste arises mainly from Polythene bags, food wraps, and beverage bottles. Use of LDPE materials increased fivefold between 2005 and 2020, contributing over 40% of municipal plastic waste (The World Bank, 2021). Utilizing LDPE as a bitumen modifier improves its rheological properties by reducing ductility and penetration, and increasing softening point (Ullah et al., 2024).

HDPE plastic is used in a wide variety of applications, including Rigid Container; Plastic Bottles; industrial drums, and pipes. A field survey in 2020 reveals that the HDPE waste generation rate in the Dhaka city corporation is 64.6 tonnes/day (The World Bank, 2021). The addition of HDPE enhances resistance to permanent deformation and increases viscosity. Furthermore, it improves creep resistance and overall mixture performance (Ghani et al., 2022).

In Bangladesh, out of the estimated 3.84 billion single-use plastic bottles used annually, only about 21.4% are successfully recycled, according to a report conducted by the Environment and Social Development Organization. The remaining 78.6% wind up in landfills, rivers, and the ocean. This indicates the high presence of PET waste in the stream. Incorporating 7.5% shredded PET in Marshall-designed asphalt achieved a 31.8% increase in stability and maintained acceptable flow values, demonstrating PET's efficacy as a bitumen modifier (Brohomo et al., 2025). PP is widely used in household and industrial products.

A compositional survey in Khulna recycling shops shows PP comprises around 60% of sorted plastic waste, due to its low cost and widespread use (Ahmed Saju et al., n.d.). Incorporating polypropylene (PP) significantly enhances bitumen's rutting performance and elasticity (Haji Seyed Javadi et al., 2025). PP reduces penetration, increases softening point and improves Marshall stability, which enhances load-bearing capacity (Jerin et al., n.d.).

In Dhaka City Corporation, both PVC and PS waste are generated at a rate of 32.3 tonnes per day. Each type individually constitutes about 5% of the total plastic waste stream(The World Bank, 2021). Studies find that the incorporation of PS in bitumen modification at different percentages significantly improves the properties of the bitumen, including its penetration, softening point, and viscosity. The plastic-modified bitumen shows improved compatibility and storage stability (Mahida et al., 2022). The addition of waste PVC increases the viscosity and stiffness of base asphalt so that the modified asphalt has better rutting resistance. Notably, when PVC is exposed to high temperatures, it can release hydrogen chloride (HCl) into the atmosphere. Therefore, necessary steps should be taken to prevent air pollution (Xu et al., 2022).

The growing amount of plastic waste in Bangladesh, mainly from LDPE, HDPE, PET, and PP, creates a serious problem of environmental harm and poor resource management. However, research shows that these discarded materials have great potential as bitumen modifiers, providing a sustainable way to improve road infrastructure. Incorporating plastic waste in certain amounts into asphalt transforms this environmental crisis into a structural asset by significantly enhancing road durability and stability.

3. METHODS OF INCORPORATION

Basically, there are two primary processes of incorporating waste plastic in pavement construction: the dry process and the wet process. Each process has its own advantages and limitations, making them suitable for different applications depending on situations. To improve performance, some researchers have altered these traditional methods; these procedures are referred to as modified processes (Noor & Rehman, 2022).

Dry Process: Generally, the dry process is applicable for all types of recycled plastics. It is conducted by incorporating the plastic waste into hot aggregates before adding asphalt (Ma et al., 2021). The first step includes heating the coarse aggregate to a temperature of 160-180 °C before gradually adding the waste plastics to the aggregate. The mixture must then be properly mixed to ensure melting and even coating (Heydari et al., 2024; Radeef et al., 2021; Vishnu & Singh, 2021). In the next step, bitumen that has been heated to 160 °C is combined with plastic-coated aggregates, cooled to 120 °C, and then laid for road surfacing (Vishnu & Singh, 2021). This approach is easy, affordable, and environmentally beneficial (Mishra & Gupta, 2020). The dry processing method is inexpensive, allows for the addition of additional plastic, doesn't require any new equipment, and may be readily implemented. Second, no fumes are generated throughout the alteration process (Noor & Rehman, 2022).

Wet Process: This process involves directly incorporating waste plastic into a hot bitumen mix. In this method, shredded plastic waste is added to bitumen and blended using a mechanical mixer at elevated temperatures (160–170 °C) based on the type of plastic and binder used to ensure uniform dispersion of the plastic within the binder. After that, heated aggregate in the same temperature range is mixed with the modified bitumen, while compaction is done at a lower temperature of about 120-130 ℃ (Ameur et al., 2025; Vishnu & Singh, 2021; Xu et al., 2022). The wet method is better for regulating the characteristics of the modified asphalt binder, but it requires specialized mixing and storage facilities (Xu et al., 2022). Waste plastic must be shredded and processed in a certain way to make it as fine as powder for the wet method, and special equipment, such as a high shear mixer to blend the plastic with high shearing speed and high temperature. As a result, the asphalt and waste plastic blend can be homogenous, and the plastic can be evenly distributed throughout the asphalt binder (Wu & Montalvo, 2021). Some studies suggest that the wet method is slightly better compared to the dry method (Haider et al., 2020).

It can be concluded that, for a developing country like Bangladesh adapting dry method is more convenient as it is more affordable and has a simple production process. Thus, further research is needed for standard guidelines and engineering expertise for the dry process.

4. IMPACT OF PLASTIC MODIFICATION ON BITUMEN CHARACTERISTICS AND FLEXIBLE PAVEMENT PERFORMANCE

Incorporating plastic waste into bituminous mixes significantly alters the physical and rheological properties of bitumen, subsequently enhancing flexible pavement performance.

4.1 Physical and Rheological Properties of Plastic-Modified Bitumen

Softening Point: Improvement of softening points is essential in Bangladesh, where heat and sun exposure cause rutting of conventional bitumen. The addition of plastic increases the softening point of bitumen. This implies that plastic-modified bitumen remains more stable at higher temperatures. This is highly effective in preventing roads from melting or becoming too soft in hot climates, thereby enhancing their durability. Bashir & Rathore (2023) observed that the softening point of the bitumen increases with the increase in the PET content. The increase was found to be 47°C and 55.5°C for the plain bitumen and PET modified bitumen, respectively. In another study by Haji Seyed Javadi et al., (2025), the softening point for base bitumen was approximately 45°C. All modifications increased the softening point. HDPE modification increased the softening point to 51°C, PP modification to 49°C, and their blend to 50°C. The addition of LDPE with steel slag in both 60/70 and 70/80 bitumen increases softening point by 8°C to 22°C, depending on the variation of bitumen grade and proportion of LDPE incorporated (Mehmood et al., 2025).

Penetration: When the plastic percentage increases, the modified bitumen's penetration often decreases, indicating a stiffer binder that is more resistant to deformation at high temperatures.(Jaysawal & Bandyopadhyaya, 2025). Research by Haji Seyed Javadi et al., (2024) found that the LDPE waste plastic modification generated a penetration value of around 48.4 dmm, which is an approximate decrease of 18.6% relative to the base bitumen. In another research by Ullah et al., (2024), for PP-modified bitumen, the penetration decreased from 67, 59, 46, and 40 at 3%, 5%, and 7% dosage, respectively. In comparison, LDPE-modified bitumen showed slightly lower values of 58, 45, and 38, respectively, at similar dosages. These reductions in penetration value indicate a stiffer binder, which is highly beneficial for resisting deformation under heavy traffic loads.

Ductility: Ductility is a critical property of bitumen, as it reflects its ability to stretch and deform under tensile stress without cracking. High ductility indicates that the binder can accommodate thermal and load-induced stresses. In Bangladesh, where temperature variations and heavy monsoon rains are common, maintaining adequate ductility is crucial to prevent cracking and ensure pavement durability. Ductility of bitumen was found to decrease with increasing content of PET, PP, and LDPE. In a study by Ullah et al., (2024), the ductility value dropped from 84 cm (neat) to 76, 66, and 58 cm with 3%, 5%, and 7% LDPE, respectively. For the same dosages of PP, the values further declined to 74, 63, and 54 cm, indicating a more significant reduction compared to LDPE. In a separate study on PET-modified binders, ductility decreased from 84 cm to 76, 67, 59, 51, and 43 cm with 2%, 4%, 6%, 8%, and 10% PET addition, respectively (Imanbayev et al., 2022). These results collectively show that all three polymers reduce ductility as their dosage increases.

Specific Gravity: Specific gravity is an important physical property of bitumen. It reflects the density and composition of the binder and influences mix design parameters. The effect of waste plastic on the specific gravity of bitumen was evaluated by Ponnada & Vamsi Krishna, (2020) using plastic-modified bitumen with varying PET contents. The specific gravity of unmodified bitumen was 0.99. With increasing plastic content, a continuous rise in specific gravity was observed, reaching 1.20, 1.31, and 1.36 at 2.5%, 5%, and 7.5% PET contents, respectively, with a maximum value of 1.50 at 10% plastic replacement. Tundeet al., (2020) also observed that for PET additions of 3, 5, 7, 9, 11, 13, 15, and 17%, the specific gravity value of plain bitumen increased by 1.0, 2.1, 3.1, 4.2, 5.2, 5.2, 6.3, and 7.3%, respectively, but was unchanged for PET additions of 1%. On the other hand, the specific gravity of bitumen decreases with the addition of expanded polystyrene (EPS), and the reduction becomes more significant as the modifier content increases. An experimental study by Murana et al., (2021)shows that specific gravity exhibits a linear downward trend with the increasing concentration of plastic modifiers. Specifically, the maximum value was recorded as 1.025 at 0% modifier, which gradually decreased to 1.012 at 10% modifier content.

Loss on Heating: Loss on heating is an important physical property of bitumen that indicates the amount of volatile components present. It reflects the binder's thermal stability and is essential for assessing bitumen quality during mixing and construction. According to a study by (Bishnoi, 2017) addition of 10% waste plastic decreases the loss on heating from 0.309 % to 0.210 %. Mohayminul Islam et al., (2021) also reported a decrease in loss on heating for the addition of both LDPE and an equal mixture of LDPE and PP. Pure LDPE showed an inconsistent reduction in weight loss with notable fluctuations at 6% and 12%. In contrast, the LDPE:PP=1:1 blend exhibited the highest thermal stability, consistently maintaining the lowest loss on heating across all percentages, reaching a minimum of 0.02% at 15% modification.

Flash and Fire Point: The flash point represents the threshold temperature at which rigorous safety measures must be implemented to prevent fire hazards during the heating process. While the fire point is the higher temperature at which it sustains burning for at least 5 seconds. Plastic-modified bitumen exhibits higher thermal stability, allowing safer high temperature mixing and laying operations. Ewa et al., (2024) showed that the integration of both PET and PS elevates the flash and fire points. Specifically, the flash point of the binder increased from 260°C to approximately 370°C for PET and 325°C for PS at a 50% concentration. A similar trend was observed for the fire point, which rose from 285°C to nearly 370°C for PET-modified and 355°C for PS-modified. Tunde et al., (2020) also observed a linear relationship between PET addition flash and fire point. They observed that the flash point of bitumen increased by more than 20% when PET was added beyond 13 %. In keeping with the same pattern, the fire point value notably rises to 17% of PET

Viscosity: Viscosity is an important property of bitumen, which represents the ability of bitumen to coat the aggregates properly. For optimal coating, the viscosity must be within an appropriate range. Measuring viscosity at 135 °C provides an assessment of the bonding quality between bitumen and aggregate. (Abdullah et al., 2017) Observed that as the percentage of plastic waste increases, the binder is getting more viscous. In that study, it was found that the viscosity of plain bitumen is 0.5 Pa·s at 135 ºC, which is less viscous compared to the addition of 6% plastic waste, which has a viscosity of 1.6 Pa·s at the same temperature. In a recent study by Ullah et al., (2024), the viscosity of 60–70 grade bitumen at 135 °C, originally measured at 0.62 Pa·s, was found to increase to 2.51 Pa·s and 2.26 Pa·s with the incorporation of PP and LDPE plastic waste, respectively. In another study of bitumen modification with recycled linear LDPE by Nizamuddin et al., (2020) at 135 °C, the viscosity value of base bitumen was 0.62 Pa·s, which then increased to 0.81 Pa·s, 1.46 Pa·s, 3.52 Pa·s, and 5.75 Pa·s at addition of 3%, 6%, 9% and 12% loading of recycled LDPE. In Bangladesh, with its heavy traffic and sometimes less-than-ideal road materials, a bitumen that's a bit thicker helps it stick better to the stones, which means reducing binder drain-off and improving pavement life.

Elastic Recovery: Elastic recovery is a fundamental rheological parameter that quantifies the ability of a bituminous binder to return to its original dimensions after being subjected to deformation. Unlike conventional bitumen, which exhibits viscous flow and permanent set under stress, Plastic Modified Bitumen is designed to exhibit enhanced elasticity. Based on the study by Singh et al., (2013), the addition of recycled LDPE significantly improves the elastic recovery of bitumen, increasing it from less than 7% to approximately 22% at a 3% concentration. When maleated bitumen is used with 9% LDPE, the recovery further enhances to as high as 57–60%. The study by Akkouri et al., (2020) indicates that while PP and PS increase the stiffness, their individual contribution to elastic recovery is lower compared to LDPE. However, the addition of Styrene-Butadiene-Styrene (SBS) as a dopant to PP and PS modified bitumen significantly enhances the elastic recovery.

Complex Shear Modulus and Phase Angle: The shear modulus (G*) and phase angle (δ) provide a comprehensive picture of the bitumen's viscoelastic behavior. G* represents the total stiffness of bitumen under cyclic loading. A higher G* value indicates better resistance to deformation, especially at higher temperatures. The phase angle (δ), on the other hand, reflects the delay between applied stress and resulting strain. It helps differentiate between elastic and viscous behavior, with $\delta = 0°$ being purely elastic and $\delta = 90°$ being purely viscous. Mashaan et al., (2022) conducted a study on the use of PET, HDPE, and LDPE as modifiers for bitumen. The Dynamic Shear Rheometer (DSR) tests showed that PET-modified binders, particularly at 6% and 8%, exhibited a significant rise in G* and a reduction in δ. In contrast, HDPE and LDPE modifications at 2% and 4% showed moderate improvement in rheological behavior, but 6% and 8% resulted in diminished performance. Mahida et al., (2022) explored the rheological impact of waste PS into bitumen. They observed that increasing PS content led to a progressive rise in G*/sin δ and a reduction in phase angle δ, both of which are indicative of better resistance to permanent deformation and improved elastic response. Another DSR test revealed that 6% HDPE-modified bitumen achieved the highest enhancement in rutting resistance, with a 95.27% increase in G*/sin δ compared to the control sample (Ghani et al., 2022).

4.2 Impact on Pavement Performance

Marshall stability and flow value: Marshall Stability and Flow values are critical indicators of the load-bearing capacity and deformation characteristics of bituminous mixtures. Studies have shown that incorporating plastic waste as a bitumen modifier significantly enhances the Marshall Stability of the mix. Conversely, the Flow value tends to decrease with plastic addition, indicating better resistance to deformation under traffic loads. For instance, inclusion of 3% LDPE plastic waste by weight of bitumen leads to an improvement in Marshall stability, increasing from 11.37 KN to 13.14 KN for 60-70 bitumen and 11.08 KN to 12.54 KN for 80-100 bitumen. However, further increasing the LDPE content to 5% and 7% generally results in a reduction in Stability compared to the 3% modified samples. Regarding the flow value, for Bitumen Grade 60-70, 3% LDPE reduced the flow from 3.5 mm to 3.0 mm. For Bitumen Grade 80-100, the Flow values reached 3.5 mm from 3.0 mm. Overall, the findings suggest that LDPE content around 3% can yield a modified asphalt mixture with enhanced Marshall Stability and controlled Flow characteristics (Mehmood et al., 2025). The improvement is also observed with PET modified bitumen (Mashaan et al., 2021). In their test, the control sample shows a Stability of approximately 13 kN. Upon the addition of 4%, 6%, and 8% PET, stability significantly increases to about 14.5 kN, 16 kN, and 17 kN, respectively. On the other hand, the downward trend was observed for the flow value from 4.2 mm to 2.2 mm with an increasing amount of PET content.

Rutting and Fatigue Resistance: Rutting refers to the permanent deformation that develops along the wheel paths of pavements due to heavy traffic loads. Mashaan et al., (2022) reported that the incorporation of 4%, 6%, and 8% PET reduces the rutting depth to approximately 8.82 mm, 5.59 mm, and 3.25 mm, respectively, compared to 12.93 mm for unmodified mixes. The maximum improvement was 25% for 8% PET-modified mixtures. Hao et al., (2024) evaluated the rutting resistance by the Hamburg Wheel Tracking Test. The control sample exhibited a mean rut depth of 16.55 mm. With LDPE modification, the value decreased to 11.06 mm at 5%, reducing to 7.21 mm at 10%, and then slightly increasing to 8.62 mm at 15%. PP modification also proved highly effective. The mean rut depth was 12.30 mm at 5% PP, significantly dropped to 4.94 mm at 10%, and further decreased to 4.20 mm at 15%. HDPE modification showed the best overall performance. The mean rut depth was 10.66 mm at 5% HDPE, reduced to 4.57 mm at 10%, and achieved the lowest rut depth of 3.57 mm with 15%. On the other hand, Fatigue resistance refers to the ability of asphalt pavement to withstand repeated traffic loading without developing cracks over time. Fonseca et al., (2022) evaluated the impact of LDPE and HDPE waste on fatigue resistance by 4 point-bending tests. The result revealed that HDPE improves fatigue resistance across all cycle levels, but LDPE reduces fatigue resistance at all stages. For 10,000 loading cycles, the strain to failure for the 6% LDPE mixture was 302 microstrain, which is significantly lower than the 365 microstrain of the reference mixture. This negative impact is also observed at 100,000 and 1,000,000 cycles, where the LDPE mixture's strain was 191 and 121 microstrain compared to the reference's 218 and 131 microstrain, respectively. Conversely, 6% HDPE increases the fatigue resistance. For 10,000 loading cycles, the strain to failure for the HDPE mixture was 372 microstrain, which is marginally higher than the 365 microstrain of the reference mixture. This positive trend continues at 100,000 loading cycles, where the strain was 239 microstrain compared to the reference's 218 microstrain. For the long-term 1,000,000 loading cycles, the HDPE mixture's strain to failure was also higher at 134 microstrain compared to the reference's 131 microstrain.

Moisture Susceptibility and Adhesion Performance: In Bangladesh, with a long rainy season, moisture damage is a major cause of pavement failure. Almeida et al., (2021) evaluated moisture susceptibility using indirect tensile strength (ITS) tests at 25 °C. Calculating the indirect tensile strength ratio (ITSR), they found that inclusion of 6% plastic waste leads to an increase in ISTR value from 102% to 108%, which indicates better resistance to moisture damage. In a separate study Movilla-Quesada et al., (2023) also evaluated moisture susceptibility by comparing the ITSR value for the unmodified and PET-modified asphalt mixture. In their test, Unmodified mixtures showed a TSR of ~89%. Inclusion of 6% PET results into TSR over 90%, and 10% PET peaked at ~97% TSR, indicating substantial improvement. Conversely, at 14%, PET TSR dropped to ~75%, and 18% and 22% PET resulted in ~78% TSR, falling below the unmodified performance.

5. ENVIRONMENTAL EFFECT AND ECONOMIC VIABILITY

Using plastic waste in roads offers significant environmental benefits. Using plastic waste in asphalt mixtures reduces CO_2 emissions, energy consumption, and environmental impact compared to the conventional method. Recycling plastic into pavements is often more environmentally beneficial than incineration or landfilling. Life Cycle Assessment (LCA) studies confirm that using plastic waste in asphalt mixtures can significantly reduce energy use, greenhouse gas emissions, and material costs, and show up to 17% lower environmental impact and improved pavement durability (Wu & Montalvo, 2021; Xu et al., 2022). The findings of LCA by (Santos et al., 2021) indicate that the wet method for PE plastic recycling results in a roughly 16% reduction in greenhouse gas emissions. Additionally, the process further mitigates impacts related to acidification, eutrophication, and photochemical oxidation. Studies have shown that replacing 8% of virgin PP with the same amount of waste PP can reduce CO2 equivalent emissions by 10.2%, while replacing SBS with waste PP can reduce emissions by 15.6%. (Xu et al., 2022). Leaching tests showed that incorporating up to 15% plastic in asphalt mixtures did not significantly increase the release of harmful substances into water, with all detected levels remaining within safe regulatory limits, minimal environmental risk to aquatic ecosystems (Hao et al., 2024). In addition to reducing greenhouse gas emissions, the incorporation of plastic waste contributes to lower energy demand during asphalt production by reducing mixing and compaction temperatures in certain applications. Studies on warm-mix asphalt incorporating waste plastic film flakes reported noticeable reductions in fuel consumption and carbon footprint while maintaining adequate mechanical performance, particularly for low- to medium-traffic roads (Almeida et al., 2021). Recycling plastic waste into pavements also supports sustainable waste management by keeping non-biodegradable materials out of landfills and uncontrolled disposal sites, which are common sources of soil and water pollution (Vishnu & Singh, 2021).

From an economic point of view, this technique reduces material costs by lowering the demand for virgin bitumen and extending pavement life, leading to long-term maintenance savings. It also minimizes landfill use and can generate additional revenue for the waste management sector (Wu & Montalvo, 2021). Life Cycle Cost Analysis (LCCA) by Hao et al., (2024) shows that an addition of 10% HDPE or PP into porous asphalt can minimize overall costs. Cheaper plastics lower material costs, while higher mixing temperatures raise production slightly, but Enhanced performance prolongs service life and lowers maintenance, making it cost-effective overall. Experimental studies on plastic-modified binders further indicate that waste plastics such as expanded polystyrene, polyethylene, and polypropylene improve stability, stiffness, and resistance to deformation, which directly contributes to longer pavement service life and reduced rehabilitation frequency (Murana et al., 2021). These performance improvements offset the slight increase in production cost, thereby enhancing the overall economic viability of plastic-modified asphalt pavements (Vishnu & Singh, 2021). Another LCCA result indicated that, considering the entire pavement structure, the use of plastic waste as a partial replacement of bitumen resulted in an overall cost reduction of about 3–

5%. In contrast, when only the wearing course was considered, a significantly higher economic benefit was observed, with cost reductions reaching approximately 17% (Lastra-González et al., 2022).

6. CONCLUSIONS

- The study finds that using plastic waste in flexible pavements can be a practical and sustainable solution for Bangladesh.
- Plastic-modified bitumen improves pavement strength, resistance to deformation and moisture damage, and extends the service life while lowering maintenance costs.
- Among the available techniques, the dry process stands out as the most suitable for Bangladesh. It is more feasible than the wet process in the local context.
- All major plastic types, including LDPE, HDPE, PET, and PP, are sufficiently available in Bangladesh's waste stream, ensuring the availability of raw material.
- Environmental assessments show that using plastic does not create significant negative impacts, as leaching remains within safe limits and the approach reduces landfill dependence, carbon emissions, and plastic pollution.
- Adopting plastic waste in road construction is not only technically feasible but also environmentally safe and socio-economically beneficial, presenting a promising pathway for sustainable infrastructure development in Bangladesh.

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