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Performance Evaluation of Bituminous Mixes Modified with Waste Plastic and Crumb Rubber for Sustainable Pavement Construction - A Review

Mr. Durgesh Katre [1], Dr. Raviraj Singh Gabbi [2]

[1] Research Scholar (Master of Technology in Structural Engineering), Department of Civil Engineering, Sardar Patel School of Engineering & Technology, Balaghat (M.P.)

[2] Professor, Department of Civil Engineering, Sardar Patel School of Engineering & Technology, Balaghat (M.P.)

Abstract: In recent years, the rapid increase in plastic waste and used rubber tyres has created serious environmental problems. At the same time, the demand for durable and high-performance road pavements is also increasing. To address both issues, many researchers have studied the use of waste plastic and crumb rubber in bituminous mixes. This review paper presents a detailed analysis of previous research studies related to modified bituminous pavements. The paper discusses the effect of waste materials on strength, durability, stability, and resistance to deformation. It is observed that modified mixes show better performance compared to conventional mixes. However, there are still some challenges related to compatibility, long-term performance, and optimum material proportions. This study helps in identifying research gaps and provides direction for future work in sustainable pavement construction.

Keywords: Waste Plastic, Crumb Rubber, Bituminous Mix, Flexible Pavement, Sustainable Construction, Marshall Stability.

I. INTRODUCTION

Road infrastructure plays a very important role in the economic development of a country. It provides connectivity between rural and urban areas, supports industrial growth, and improves transportation efficiency. In developing countries like India, the demand for high-quality and durable road networks is increasing rapidly due to population growth, urbanization, and increased vehicular traffic. Flexible pavements are widely used in road construction because they are economical, easy to construct, and require less initial investment compared to rigid pavements. These pavements consist of bituminous layers which provide flexibility and load distribution. However, conventional flexible pavements are facing several problems such as rutting, fatigue cracking, potholes, and permanent deformation due to repeated traffic loading and varying environmental conditions [9].

The performance of bituminous pavements is greatly affected by temperature variations, moisture infiltration, and traffic intensity. At high temperatures, bitumen becomes soft, leading to rutting and deformation, while at low temperatures, it becomes brittle and causes cracking. In addition, water penetration weakens the bond between aggregates and bitumen, resulting in stripping and reduced pavement life. Therefore, there is a need to improve the engineering properties of bituminous mixes to enhance their strength, durability, and resistance to environmental conditions [4].

At the same time, environmental issues related to solid waste management are increasing at an alarming rate. Plastic waste and waste tyres are among the major contributors to environmental pollution. Plastic materials such as polyethylene (PE), polypropylene (PP), and polyethylene terephthalate (PET) are non-biodegradable and remain in the environment for hundreds of years. Similarly, waste tyres generate crumb rubber, which is difficult to dispose of and creates land and air pollution. Improper disposal methods such as open dumping and burning lead to serious environmental and health hazards [22].

To overcome these problems, researchers have explored the use of waste plastic and crumb rubber in bituminous pavement construction. Waste plastic can be used either by coating aggregates (dry process) or by modifying bitumen (wet process), while crumb rubber is generally used as a modifier in bitumen. These waste materials improve the binding properties of bitumen and enhance the performance of asphalt mixtures. Studies have shown that plastic-modified bitumen improves resistance to rutting, moisture damage, and aging, while crumb rubber improves elasticity, fatigue resistance, and flexibility of the pavement [3], [6].

The incorporation of waste materials in bituminous mixes also provides a sustainable solution for waste management. It reduces the consumption of natural resources such as aggregates and bitumen, lowers construction costs, and minimizes environmental pollution. According to various studies, modified bituminous mixes exhibit higher Marshall Stability, improved load-carrying capacity, and better durability compared to conventional mixes [13], [25]. In addition, the use of waste plastic in road construction is also supported by guidelines such as IRC: SP:98, which promotes the use of plastic waste for sustainable pavement development in India [10].

Several researchers have conducted experimental and review-based studies to evaluate the performance of modified bituminous mixes. These studies indicate that the use of waste plastic and crumb rubber significantly enhances pavement properties. However, the results vary depending on the type and percentage of waste materials used, mixing method, and environmental conditions. There is still a need to identify optimum proportions and study long-term performance under field conditions [16], [27].

Despite the advantages, some challenges still exist in the use of waste materials in bituminous pavements. Issues such as compatibility between plastic and bitumen, increased viscosity at higher rubber content, and lack of standard design procedures need further investigation. Moreover, environmental concerns such as microplastic generation and leaching effects also require detailed study [22].

Therefore, this review paper aims to analyze previous research work related to the use of waste plastic and crumb rubber in bituminous pavements. The study focuses on understanding the effects of these materials on pavement performance, identifying key findings, and highlighting research gaps for future work. This will help in developing sustainable, durable, and cost-effective pavement solutions for modern infrastructure development.

II. LITERATURE REVIEW

The literature review presents a detailed study of previous research work related to the use of waste plastic and crumb rubber in bituminous pavements. Many researchers have focused on improving pavement performance, durability, and sustainability by incorporating waste materials.

[1] Naeem Aziz Memon et al. (2026) studied the optimization of crumb rubber modified bitumen (CRMB) using different blending parameters. The researchers analyzed factors such as temperature, mixing speed, time, and rubber size to improve binder performance. Laboratory tests like penetration, viscosity, and softening point were conducted. The results showed that adding 15% crumb rubber improved durability by increasing stiffness and reducing penetration. The study concluded that proper blending conditions are very important for achieving high-performance asphalt mixtures.

[2] Mohammed Aziz Hameed (2026) investigated the use of plastic waste and crumb rubber as fine aggregate replacement in asphalt mixtures. Different proportions were tested and evaluated using Marshall Stability and rutting tests. The results showed that 3% crumb rubber and 6% plastic waste provided optimum performance. The modified mix showed higher stability and better resistance to deformation. The study highlighted that waste materials can improve strength and sustainability in pavement construction.

[3] Ivana Ban et al. (2025) examined crumb rubber modified asphalt in both dense-graded and gap-graded mixtures. The study used 18% crumb rubber in the binder and analyzed volumetric and mechanical properties. Tests like Marshall stability and density were conducted. The results showed better performance in stone mastic asphalt (SMA) mixtures compared to conventional mixes. The study emphasized that correct binder content is very important for achieving good performance.

[4] Song Xinze and Cai Kejian (2025) presented a review on waste plastic modified asphalt. The study discussed types of plastics, preparation methods, and compatibility issues with bitumen. It was found that plastic improves high-temperature performance and durability of pavements. However, compatibility between plastic and bitumen remains a challenge. The study suggested more research on long-term field performance and recycling techniques.

[5] Sanjana Sharma et al. (2025) studied the effect of different waste materials like plastic, crumb rubber, and waste oil in bituminous mixes. Various laboratory tests were conducted to analyze binder properties. The results showed improved durability, strength, and performance of modified mixes. The study also highlighted cost reduction and environmental benefits. It concluded that optimum percentage of waste materials is important for best results.

[6] Mayank Chaturvedi and Prof. Dinesh Jaiswal (2025) investigated PET plastic waste in bituminous mixes. Different percentages of PET were used and tested using Marshall Stability. The results showed improved strength and stability compared to conventional mixes. The modified mix also showed better durability and performance. The study concluded that plastic waste can be effectively used in road construction.

[7] Khan and Tabassum (2025) studied crumb rubber modified bitumen using different percentages. Laboratory tests like penetration, ductility, and Marshall stability were conducted. The results showed that 10% crumb rubber provided the best performance. The study observed improved stiffness, fatigue resistance, and reduced binder content. It concluded that CRMB is economical and sustainable for pavement construction.

[8] Shah et al. (2025) presented a comprehensive review on plastic waste in asphalt. The study analyzed different plastic types and modification methods. It was found that plastic improves rutting resistance and fatigue life of pavements. Environmental benefits like reduced carbon emission were also highlighted. However, issues like microplastic pollution and compatibility need further research.

[9] Kumar et al. (2024) studied mixed waste plastic in bituminous mixes. Different plastic percentages were tested using Marshall and tensile strength tests. The results showed improved mechanical properties and durability. Optimum performance was achieved at 7–10% plastic content. The study concluded that plastic waste enhances pavement life and strength.

[10] Kernia and Tangri (2024) investigated crumb rubber as a partial replacement in bitumen. The study used different percentages and evaluated performance using rutting and skid resistance tests. The results showed improved strength and durability. Modified mixes also showed better resistance to deformation. The study concluded that crumb rubber improves pavement life and sustainability.

[11] Mthembu (2024) reviewed the use of recycled plastics in asphalt pavements. The study analyzed various research findings and performance characteristics. It was found that plastic improves strength and durability. The study also highlighted environmental benefits. It concluded that recycled plastic is a promising material for sustainable roads.

[12] Mittal et al. (2024) studied industrial waste in bituminous mixes. Materials like LDPE, waste oil, and crumb rubber were used. Marshall tests were conducted to evaluate performance. The results showed improved stability and flow values at optimum proportions. The study concluded that waste materials can improve mix performance but excess use may reduce quality.

[13] Bastola et al. (2024) investigated different types of plastic in hot mix asphalt. Laboratory tests showed improved stability and moisture resistance. Plastic-coated aggregates improved bonding properties. The study also showed reduction in bitumen requirement. It concluded that plastic waste can enhance performance and sustainability.

[14] Nandal et al. (2023) reviewed the use of waste materials in flexible pavement. The study analyzed plastic, rubber, and industrial waste. It was found that waste materials improve durability and strength. Environmental benefits like waste reduction were also highlighted. The study suggested more research for large-scale implementation.

[15] Ramshankar et al. (2023) studied construction demolition waste and plastic in asphalt mixes. The study used Marshall Stability tests for evaluation. The results showed improved strength at optimum proportions. The use of waste reduced natural resource consumption. The study concluded that it is a sustainable solution for road construction.

[16] Singh and Jala (2023) investigated PET and rubber powder in bitumen. Different percentages were tested in the study. The results showed improved stiffness and resistance to deformation. Optimum performance was achieved at around 6%. The study concluded that waste materials can replace polymer modifiers effectively.

[17] Duan et al. (2022) reviewed crumb rubber modified asphalt. The study analyzed preparation methods and performance characteristics. It was found that rubber improves durability and resistance. However, high content reduces workability. The study concluded that optimization is necessary.

[18] Prathibha and Karthik (2022) studied plastic and crumb rubber in bituminous mixes. Laboratory tests showed improved strength and durability. Optimum results were achieved at 10% plastic and rubber content. The modified mix showed better load-carrying capacity. The study concluded that waste materials improve pavement performance.

[19] Kumar et al. (2022) studied waste polythene fiber in asphalt mixes. The study showed improved Marshall stability and reduced voids. Plastic coating reduced moisture damage. The results indicated better durability and performance. The study concluded that polythene waste is useful in pavement construction.

[20] Aldagari et al. (2022) compared plastic and rubber modified bitumen. The study showed that plastic improves deformation resistance. Rubber improves fatigue resistance. Both materials improved overall performance. The study suggested combined use for better results.

III. RESEARCH GAP

From the detailed review of previous research studies, it is clear that significant work has been carried out on the use of waste plastic and crumb rubber in bituminous pavements; however, several important gaps still exist which need further investigation. Most of the available studies are limited to laboratory-scale experiments, and there is a lack of long-term field performance data under actual traffic and environmental conditions, which is essential for practical implementation. Although many researchers have suggested optimum percentages of plastic and crumb rubber, there is no universally accepted standard value, as the results vary depending on material type, mix design, and climatic conditions. The compatibility issue between bitumen and different types of plastic waste is still not fully resolved, which may affect the uniformity and stability of the modified mix. In the case of crumb rubber, higher percentages tend to increase viscosity, making mixing and compaction difficult, but this aspect has not been standardized properly. Moreover, very limited studies have focused on the combined use of plastic waste and crumb rubber together, and their synergistic effects on pavement performance are not fully understood. Environmental concerns such as microplastic release, leaching of harmful substances, and long-term ecological impacts have also not been studied in detail. Additionally, there is a lack of proper design guidelines, codal provisions, and standardized procedures for the use of waste-modified bituminous mixes in large-scale projects. The effect of these modified materials on recyclability, maintenance practices, and life-cycle cost analysis of pavements is also not adequately explored. Therefore, further research is required to address these gaps and to develop reliable, safe, and sustainable solutions for the use of waste plastic and crumb rubber in flexible pavement construction.

CONCLUSION

Based on the review of various research studies, it can be concluded that the use of waste plastic and crumb rubber in bituminous mixes significantly improves pavement performance. Modified mixes show higher Marshall Stability, better resistance to rutting, improved durability, and longer service life compared to conventional mixes. The use of waste materials also provides environmental benefits by reducing plastic pollution and conserving natural resources. It is an economical and sustainable solution for road construction. However, challenges such as proper material selection, compatibility issues, and lack of field studies still exist. Therefore, further research is required to standardize the use of these materials and ensure long-term performance. Overall, waste plastic and crumb rubber modified bituminous mixes have great potential for sustainable pavement construction and should be promoted in future infrastructure projects.

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