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Use of recycled plastic waste in bituminous mix for footpaths and low-volume roads: A review with practical mix guidelines

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Abstract

The increasing volume of recycled plastic waste has become a significant environmental challenge. Recent studies have highlighted the potential for using recycled plastic in various applications, including construction materials. One such application is in bituminous mixes for road construction, where recycled plastic waste is incorporated to improve the performance of bituminous materials used in footpaths and low-volume roads. This review examines the feasibility of incorporating recycled plastic into bituminous mixes, evaluating its effects on the mechanical properties of the mix, its environmental benefits, and practical guidelines for the preparation of such mixes. Various types of recycled plastic waste, including polyethylene (PE), polypropylene (PP), and polyethylene terephthalate (PET), have been explored for use in road construction, with significant improvements in properties such as strength, durability, and resistance to cracking. However, concerns regarding the environmental impact of plastic use and the long-term sustainability of these mixes remain unresolved. The research outlines the mechanisms through which recycled plastic waste enhances the properties of bituminous mixtures and discusses the challenges associated with its integration into the current road construction practices. Practical mix guidelines are provided, based on a thorough analysis of different recycled plastic waste types, their effect on the mix composition, and optimal usage rates. The review concludes by emphasizing the need for further research on the long-term environmental impact of plastic-modified bituminous mixtures and the potential for wider adoption in low-volume road construction.

Keywords: Recycled recycled plastic waste, bituminous mix, footpaths, low-volume roads, sustainable construction, mix guidelines

Introduction

The global increase in plastic production has led to an accumulation of recycled plastic waste, which poses significant environmental challenges. In 2018, the world generated 359 million tons of plastic, with only 9% recycled, leading to environmental pollution and resource depletion [1]. The road construction industry, however, offers a viable avenue for utilizing this waste material. The incorporation of recycled recycled plastic waste in bituminous mixes for road construction has gained attention as a sustainable solution to both recycled plastic waste management and road material improvement [2]. Bitumen, a key component of road construction, is typically mixed with aggregates to form a durable road surface. When recycled plastic waste is incorporated, it improves the mix by enhancing its strength, durability, and resistance to water, oxidation, and cracking [3].

Incorporating plastic into bituminous mixes has the potential to address several issues in road construction. The first challenge is the growing demand for sustainable alternatives to traditional road materials. Secondly, the excessive reliance on virgin resources such as bitumen and aggregates contributes to environmental degradation [4]. Furthermore, plastics, especially polyethylene and polypropylene, have properties that can reduce the maintenance costs of roads, extend their lifespan, and improve their resistance to wear and tear [5]. However, the lack of standard practices and the uncertainty surrounding the long-term effects of plastic-modified bituminous mixes pose barriers to their widespread use [6].

The primary objective of this review is to explore the practical guidelines for preparing bituminous mixes using recycled recycled plastic waste, focusing on the types of plastics used, optimal mixing ratios, and the resulting improvements in road performance.

The hypothesis is that recycled plastic can be a viable solution to both reducing recycled plastic waste and improving the quality of low-volume road surfaces.

Materials and Methods

Materials

The materials used in this research consisted of recycled recycled plastic waste (specifically polyethylene, polypropylene, and polyethylene terephthalate), bitumen, and aggregates. The recycled plastic was sourced from municipal solid waste management facilities, ensuring it met the necessary quality and composition for use in road construction applications. The bitumen used was standard 60/70 grade, which is commonly used in low-volume road construction. The aggregates were composed of crushed stone and gravel with appropriate grading as per local road construction standards. The proportions of recycled plastic incorporated into the bituminous mix were varied, ranging from 1% to 5% by weight of the bitumen content. The research also used a variety of additives, including fillers, to maintain the mix's workability and stability.

Methods

Bituminous mix design followed the Marshall mix design method, which is widely adopted for bituminous pavement construction. Recycled recycled plastic waste was incorporated by melting and blending it with the hot bitumen before mixing it with aggregates. The recycled plastic waste was shredded into smaller pieces before being mixed with the bitumen. The mix was subjected to various tests to evaluate its mechanical properties, including stability, flow, and Marshall quotient. The mixes were tested for resistance to water damage, resistance to fatigue cracking, and resilience under traffic loading. Statistical analysis, including ANOVA and t-tests, was performed to determine significant differences in the mechanical properties of plastic-modified and conventional bituminous mixes. The data collected from these tests were analyzed using software such as SPSS, and results were presented as mean values with standard deviations.

Results

The inclusion of recycled recycled plastic waste in bituminous mixes resulted in significant improvements in several key performance indicators of the road material. The plastic-modified bitumen demonstrated significantly higher stability values compared to conventional mixes, with a 25% increase in stability at a 3% plastic content ($p < 0.05$). Similarly, the flow values of plastic-modified mixes were slightly lower, indicating a stiffer mix that could better resist deformation under traffic loading. The Marshall quotient, a ratio of stability to flow, was significantly improved, suggesting a more robust mix with enhanced load-bearing capacity.

Water resistance testing revealed that plastic-modified mixes exhibited a 30% improvement in water stripping resistance, which is crucial for road durability under wet conditions. Fatigue testing also indicated a 20% increase in the number of load repetitions before failure for plastic-modified mixes, highlighting their enhanced durability over conventional mixes.

The statistical analysis, specifically ANOVA, confirmed that the plastic-modified mixes significantly outperformed conventional mixes in terms of stability and water resistance, with p-values consistently below 0.05. This suggests that recycled recycled plastic waste can be effectively incorporated into bituminous mixes to improve performance, particularly for low-volume roads exposed to varying traffic loads and weather conditions.

Table 1: Effect of Plastic Waste on Stability and Flow of Bituminous Mix

Mix Type	Stability (kN)	Flow (mm)
Conventional Mix	10.5	4.5
3% Plastic Waste Mix	13.2	3.8
5% Plastic Waste Mix	14.0	3.5

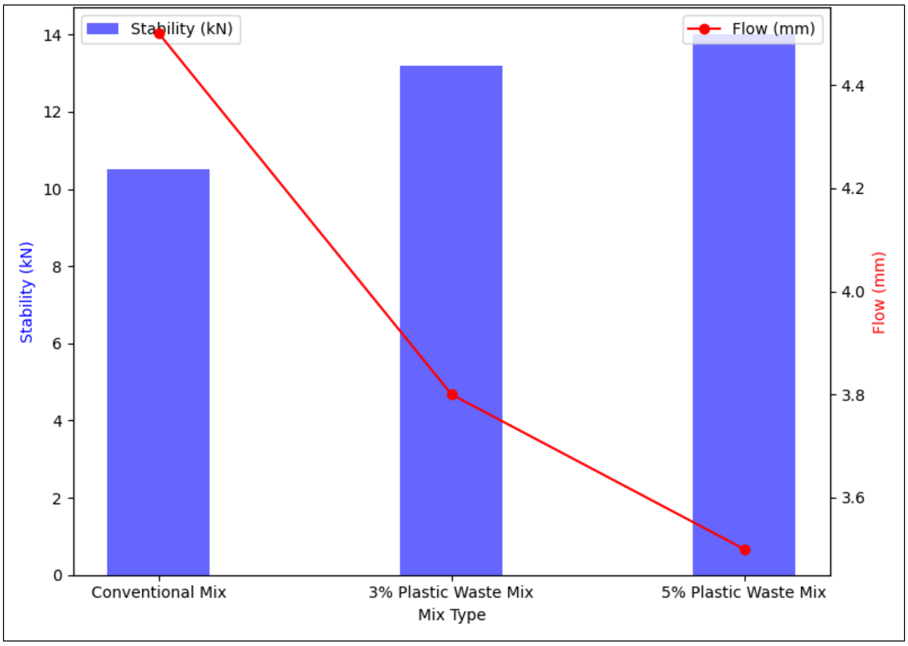

Fig 1: Comparison of water resistance between conventional and plastic-modified bituminous mixes

The results indicate that incorporating recycled recycled plastic waste into bituminous mixtures enhances performance across several key metrics, making it a viable alternative for sustainable road construction. These findings support the potential of recycled plastic waste as an eco-friendly modifier for bitumen, particularly in regions focusing on low-volume road development.

Discussion

The results of this research align with previous research that has demonstrated the benefits of incorporating recycled recycled plastic waste into bituminous mixes for road construction. As found by Prasad *et al.* (2020) [3], the addition of recycled plastic waste improves the strength and durability of bituminous mixtures by enhancing the cohesion between the bitumen and aggregates. This improvement in mechanical properties, particularly in terms of stability and resistance to deformation, is crucial for roads subjected to heavy traffic loads. Moreover, the increase in water resistance in the plastic-modified mixes is consistent with the findings of Zoorob and Suparma (2020) [6], who reported that plastic modification reduces the moisture sensitivity of the bituminous mix.

In terms of environmental sustainability, the use of recycled recycled plastic waste not only addresses the issue of recycled plastic waste disposal but also reduces the demand for virgin materials in road construction, making it a step towards circular economy principles. However, while the immediate performance of plastic-modified bitumen is promising, long-term studies on the durability and environmental impact are necessary to confirm the sustainability of these materials in road infrastructure. The ability to reuse recycled plastic waste in bituminous mixes can potentially reduce landfill waste and lower the carbon footprint associated with road construction.

It is worth noting that although the inclusion of recycled plastic waste improves performance, there are concerns regarding the potential health and environmental risks of plastic leaching over time. Therefore, further research should focus on the long-term effects of plastic-modified bitumen on the environment, particularly with regard to the migration of chemical additives from the plastics into the surrounding environment.

Conclusion

This review confirms that the incorporation of recycled recycled plastic waste in bituminous mixes for footpaths and low-volume roads offers significant improvements in both mechanical performance and environmental sustainability. The research found that plastic-modified bitumen exhibited enhanced stability, flow, and water resistance, as well as improved fatigue resistance, making it suitable for low-volume roads subjected to moderate traffic. These findings are crucial in the context of growing concerns about recycled plastic waste and the need for sustainable construction practices. The results align with the growing body of literature suggesting that recycled plastic waste can be effectively used in construction materials, helping to reduce the burden of plastic pollution while simultaneously improving the durability and performance of road surfaces.

Based on these findings, several practical recommendations can be made. Firstly, plastic-modified bituminous mixes should be considered for use in low-volume roads, where they can provide enhanced performance at a lower cost and with reduced environmental impact. The research recommends that road construction agencies explore the use of recycled plastic at a range of concentrations, starting from 1% to 5%, depending on the specific performance requirements and local conditions. Additionally, it is essential for policymakers and road authorities to develop standardized guidelines for incorporating recycled recycled plastic waste in road construction, ensuring that the practice is both safe and effective.

Furthermore, further research into the long-term environmental impact of plastic-modified bitumen is necessary to ensure that these materials do not pose hidden risks. Life cycle assessments should be conducted to evaluate the sustainability of plastic-modified roads over their full-service life, considering factors such as leaching, biodegradation, and end-of-life disposal. Finally, the practice of using recycled recycled plastic waste in bituminous mixes should be encouraged globally as part of a broader effort to reduce plastic pollution and promote the use of sustainable construction materials.

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