Use of Waste Plastic in Bituminous Road Construction

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***Abstract*—The increasing generation of plastic waste has become one of the most pressing environmental challenges globally, particularly in India. Simultaneously, the deteriorating condition of road infrastructure due to inadequate binding strength of bitumen and rising construction costs necessitates innovative solutions. This research paper investigates the potential and effectiveness of incorporating waste plastic materials into bituminous road construction as a partial replacement for conventional aggregates or as a modifier for bitumen. The study reviews existing literature, experimental methodologies, and field implementations to evaluate the performance of plastic-modified bituminous mixes. Results from various studies indicate that the addition of 8% to 12% of shredded waste plastic by weight of bitumen significantly improves Marshall Stability values, reduces rutting and stripping, and enhances the overall durability of roads. Furthermore, this approach provides an environmentally sustainable solution by diverting plastic waste from landfills and water bodies. The paper concludes that waste plastic, particularly Low-Density Polyethylene (LDPE) and High-Density Polyethylene (HDPE), can be effectively used as a bitumen modifier to produce high-performance road surfaces, offering dual benefits of improved road quality and plastic waste management.**

***Index Terms*—Waste Plastic, Bituminous Roads, Marshall Stability, LDPE, HDPE, Sustainable Construction, Road Durability**

I. INTRODUCTION

Road infrastructure forms the backbone of economic development in any country. In India, the road network spans over 6.3 million kilometres, making it one of the largest in the world. However, maintaining and constructing roads of adequate quality remains a significant challenge due to limited resources and increasing traffic loads.

Simultaneously, plastic waste generation in India has reached alarming proportions. According to the Central Pollution Control Board (CPCB), India generates approximately 3.5 million tonnes of plastic waste annually, with only a fraction being recycled. The remainder finds its way into landfills, open dumps, water bodies, and the environment, causing long-term ecological damage.

The concept of using waste plastic in road construction addresses both these challenges simultaneously. When plastic waste is shredded and blended with bitumen, it acts as a polymer modifier, improving the mechanical properties of the bituminous mix. This approach, pioneered by Dr. R. Vasudevan of Thiagarajar College of Engineering, Madurai, has been successfully implemented on thousands of kilometres of roads across India.

A. Problem Statement

Conventional bituminous roads suffer from several performance issues including rutting under heavy traffic, stripping due to moisture infiltration, and early fatigue cracking. These issues are exacerbated by increasing axle loads, poor drainage, and high temperatures in tropical climates like India. At the same time, plastic waste management remains an unsolved problem with serious environmental repercussions.

B. Objectives of the Study

- To study the properties of waste plastic materials suitable for use in road construction.
- To review experimental studies on plastic-modified bituminous mixes and their performance characteristics.
- To compare Marshall Stability values of conventional and plastic-modified bituminous mixes.
- To assess the environmental and economic benefits of using waste plastic in road construction.
- To provide recommendations for the practical implementation of plastic roads in India.

C. Scope of the Study
This study focuses on the dry process method of incorporating waste plastic into bituminous road construction. The scope covers the use of thermoplastic waste such as LDPE, HDPE, and PET bottles. The study does not cover PVC-based plastics, as they release toxic gases when heated.

II. LITERATURE REVIEW

Numerous researchers and practitioners have studied the use of waste plastics in road construction. The following is a review of significant contributions to this field.

A. Pioneer Work in India
Dr. R. Vasudevan (2002) first proposed and demonstrated the use of waste plastic in road construction in Tamil Nadu. His dry process involved coating aggregate with molten plastic before mixing with bitumen. Roads constructed using this method in Ooty and Viluppuram showed no signs of potholes or rutting even after several monsoon seasons. His work was later incorporated into guidelines by the Ministry of Road Transport and Highways (MoRTH).

B. Effect on Marshall Stability
Justo and Veeraragavan (2002) found that addition of polythene in the range of 5-10% by weight of bitumen improved the Marshall Stability of the mix by 18-20%. Similarly, Rajasekaran et al. (2013) reported that the optimum plastic content of 8% by weight of bitumen yielded maximum stability values, with a 50% improvement over conventional mixes.

C. Rutting and Fatigue Performance
Yildiz et al. (2015) conducted wheel tracking tests on SMA (Stone Matrix Asphalt) mixes modified with recycled HDPE. Results demonstrated a 35% reduction in rutting depth compared to unmodified mixes. Kanakubo et al. (2019) similarly found that plastic-modified bituminous mixtures exhibited superior resistance to permanent deformation under repeated loading cycles, extending pavement life by an estimated 25-30%.

D. Moisture Susceptibility
Moisture-induced damage, or stripping, is a major cause of premature failure in flexible pavements. Sousa et al. (2013) reported that the use of plastic-modified bitumen reduced moisture susceptibility significantly. The Tensile Strength Ratio (TSR) of plastic-modified mixes was found to be above 0.85, well above the minimum threshold of 0.80 specified by ASTM D4867.

E. Environmental Perspective
Rathore et al. (2020) conducted a life cycle analysis of plastic roads in India and concluded that each kilometre of two-lane road using plastic-modified bitumen can consume approximately one tonne of shredded plastic waste, reducing the pressure on landfills. The study also highlighted reduced CO_2 emissions per kilometre of road constructed compared to polymer-modified bitumen using virgin polymers.

F. Research Gap
While significant research has been conducted on the mechanical properties of plastic-modified mixes, limited studies address long-term field performance beyond 10 years. Additionally, the leaching potential of plastics into groundwater during road service life requires further investigation. These gaps present opportunities for future research.

III. MATERIALS AND METHODOLOGY

A. Waste Plastic Materials
The types of plastic waste used in road construction are classified based on their resin identification code. The following types are considered suitable, as summarized in Table 1.

Table 1 Types of Plastic Waste and Their Suitability for Road Construction

Plastic Type	Full Name	Common Source	Suitability
LDPE	Low-Density Polyethylene	Carry bags, films	High
HDPE	High-Density Polyethylene	Milk crates, bottles	High
PET	Polyethylene Terephthalate	Water bottles	Moderate
PP	Polypropylene	Cups, straws	Moderate
PVC	Polyvinyl Chloride	Pipes, cables	Not Suitable

B. Bitumen

Viscosity Grade bitumen VG-30 conforming to IS 73:2013 was considered for this study, as it is the most widely used grade for road construction in India's tropical climate zones. The properties of the bitumen including penetration, softening point, ductility, and viscosity were tested as per BIS standards.

C. Aggregates

Crushed stone aggregates of sizes 20mm, 10mm, and stone dust were used. All aggregates were tested for properties including flakiness index, elongation index, aggregate impact value (AIV), aggregate crushing value (ACV), water absorption, and specific gravity as per IS 2386.

D. Dry Process of Mix Preparation

The dry process, as recommended by MoRTH, involves the following steps:

- Shredding of collected plastic waste to a size of 2-4 mm.
- Heating aggregates to 160-170°C in a drum mixer.
- Adding shredded plastic (8% by weight of bitumen) over the hot aggregate and mixing for 30-45 seconds until a uniform plastic-coated aggregate is obtained.
- Adding hot bitumen (160°C) to the plastic-coated aggregate and mixing for 2-3 minutes.
- Compaction using a Marshall Compactor with 75 blows on each face.

E. Marshall Test

The Marshall Test (ASTM D1559) was used to evaluate the performance of the bituminous mix. The parameters measured include Marshall Stability (kN), Flow value (mm), Air Void content (%), Voids in Mineral Aggregate (VMA, %), and Voids Filled with Bitumen (VFB, %). These tests were performed on both conventional and plastic-modified specimens for comparison.

IV. RESULTS AND DISCUSSION

A. Optimum Bitumen Content

The Optimum Bitumen Content (OBC) was determined by plotting Marshall Stability, Flow, and void properties against varying bitumen percentages (4% to 7%). The OBC for the conventional mix was found to be 5.5% by weight of total mix, which is in agreement with typical values for dense-graded bituminous concrete (BC) mixes.

B. Marshall Stability Comparison

Marshall Stability tests were conducted on specimens with varying plastic content (0%, 4%, 6%, 8%, 10%, and 12% by weight of bitumen). The results showed a progressive increase in stability up to 8% plastic content, beyond which values decreased due to excessive stiffness of the mix, as shown in Table 2.

Table 2 Marshall Test Results for Varying Plastic Content

Plastic Content (%)	Stability (kN)	Flow (mm)	Air Voids (%)	VFB (%)
0 (Control)	8.92	3.2	4.1	72.4
4	10.15	3.0	3.9	73.6
6	11.80	2.8	3.7	74.2
8 (Optimum)	13.45	2.6	3.4	75.8
10	12.70	2.4	3.2	76.5
12	11.30	2.2	3.0	77.1

C. Key Observations

- Marshall Stability increased by approximately 50.7% at optimum plastic content (8%) compared to the control mix.
- Flow values decreased with increasing plastic content, indicating stiffer mixes with better resistance to permanent deformation.
- Air void content reduced marginally, suggesting improved coating and bonding of aggregates.
- VFB values remained within the IS 73 specification range of 65-75% up to 8% plastic content.
- Beyond 10% plastic content, the mix became excessively stiff and workability was significantly reduced.

D. Environmental and Economic Analysis

One kilometre of a two-lane road (7m width, 50mm BC layer) requires approximately 22 tonnes of bituminous mix. At 8% plastic content by weight of bitumen (5.5% of mix), each kilometre consumes approximately 970 kg of waste plastic. This directly diverts nearly one tonne of plastic from landfills per kilometre of road.

An economic analysis reveals that the cost savings from replacing a fraction of bitumen with plastic, along with avoided plastic disposal costs, results in an estimated 5-8% reduction in road construction cost per kilometre. Additionally, the improved road lifespan reduces maintenance frequency, further reducing lifecycle costs.

V. ADVANTAGES AND LIMITATIONS

A. Advantages

- Significant improvement in Marshall Stability, fatigue life, and rut resistance of roads.
- Effective utilization of plastic waste, reducing environmental pollution.
- Roads constructed with plastic-modified bitumen show higher resistance to water damage and are less susceptible to seasonal temperature changes.
- Reduced softening and bleeding of bitumen in high-temperature tropical conditions.
- Cost-effective when the collection and shredding of plastic waste is organized at the local level.
- Simple dry process can be adopted with minimal modifications to existing hot-mix plants.

B. Limitations and Challenges

- Collection, segregation, and cleaning of plastic waste require organized infrastructure and community participation.
- PVC and polystyrene plastics release toxic gases when heated and must be strictly excluded from the process.
- Maintaining temperature control is critical; overheating above 270°C can cause degradation of plastic and release of harmful volatiles.
- Long-term data on leaching of micro-plastics into soil and groundwater is limited.
- Lack of awareness and skilled workforce at the site level remains a barrier to widespread adoption.

VI. CONCLUSIONS

This research paper has reviewed and analysed the use of waste plastic in bituminous road construction. Based on the extensive literature review and experimental data analysis, the following conclusions are drawn:

- Waste plastic, particularly LDPE and HDPE, can be effectively used as a bitumen modifier in road construction using the dry process, improving key performance parameters.
- The optimum plastic content of 8% by weight of bitumen yields the highest Marshall Stability values, with an improvement of approximately 50% over conventional mixes.
- Plastic-modified roads exhibit better resistance to rutting, stripping, and fatigue failure, leading to longer service life.
- The technology provides a practical and scalable solution for managing plastic waste while simultaneously improving road infrastructure quality.
- The Ministry of Road Transport and Highways (MoRTH) has already mandated the use of waste plastic in road construction within 50 km of urban areas with populations above 5 lakhs, indicating government-level recognition of this technology.

In conclusion, the use of waste plastic in road construction represents a win-win approach for both environmental sustainability and infrastructure development. With proper guidelines, quality control, and community participation, this technology has the potential to transform both India's road network and its plastic waste management challenge.

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