Sustainable Surface Courses Investigation of Plastic Waste as Modifier in Bitumous Concrete for Road Infrastructure

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Abstract - This study investigated the effectiveness of waste plastics, specifically Low-Density Polyethylene (LDPE) and High-Density Polyethylene (HDPE), as modifiers in bituminous concrete for flexible pavement applications. Rapid growth in plastic consumption and its non-biodegradable nature has intensified environmental concerns, motivating the reuse of plastic waste in road construction. In this work, shredded LDPE and HDPE were incorporated into bituminous mixes using dry, wet, and combined processes. Laboratory evaluations, including Marshall Stability, flow, indirect tensile strength, and compressive strength tests, were conducted to assess the performance of modified mixes. Results showed that plastic-modified bituminous concrete exhibited enhanced stability, durability, and resistance to rutting and cracking compared to conventional mixes. Optimum plastic content was identified as 8% for the dry process and 6% for the wet process. The study concludes that the addition of waste plastics improves mechanical properties, reduces bitumen consumption, and provides a sustainable and economical approach for flexible pavement construction.

***Key Words*:** Waste plastic, LDPE, HDPE, bituminous concrete, Marshall Stability, flexible pavement, plastic modification, sustainable roads.

1. INTRODUCTION

The rapid pace of industrialization and urbanization has led to a substantial increase in solid waste generation, particularly plastic waste, which poses major environmental challenges due to its non-biodegradable nature. Plastics are widely used in packaging, household products, and industrial applications, resulting in large quantities of post-consumer waste that often contributes to pollution and health hazards. The growing concern over improper plastic disposal has emphasized the need for sustainable waste management approaches, aligning with national initiatives such as the “Swachh Bharat Abhiyan” and the 4R’s policy—reduce, reuse, recycle, and recover.

Road transportation plays a critical role in economic development, with flexible pavements forming the majority of road infrastructure in India. However, increasing traffic loads, harsh climatic variations, and rising construction costs demand the development of cost-effective and durable pavement technologies. Flexible pavements consist of multiple layers, among which the surface course is most susceptible to traffic-induced distresses such as rutting, cracking, and deformation.

Recent studies have indicated that incorporating waste plastics in bituminous concrete enhances pavement performance and offers a viable solution for reducing plastic pollution. Plastics such as LDPE and HDPE have demonstrated significant potential as modifiers due to their proven ability to improve the ductility, stiffness, and durability of bituminous mixes. Utilizing waste plastic in bituminous concrete reduces bitumen consumption, enhances binder properties, and contributes to sustainable road construction practices.

This study focuses on the utilization of LDPE and HDPE plastic waste as partial replacements for bitumen in flexible pavements. By employing dry, wet, and combined mixing processes, the research evaluates the impact of plastic modification on mechanical and volumetric characteristics of bituminous mixes. The objective is to develop a sustainable, economical, and environmentally responsible pavement material that improves road quality while effectively managing plastic waste.

1.1 OBJECTIVES OF THE STUDY

- To evaluate the suitability of waste plastics—specifically LDPE and HDPE—as modifiers in bituminous mixes for flexible pavement construction.
- To recommend a durable bituminous mix that exhibits improved resistance against common pavement distresses such as rutting and cracking.
- To determine the Optimum Binder Content (OBC) for various combinations of conventional and plastic-modified bituminous mixes.
- To assess the mechanical performance of plastic-modified mixes through tensile strength, compressive strength, and Marshall Stability analyses.
- To conduct a comparative analysis between plastic-modified and conventional bituminous mixes in terms of strength, durability, and volumetric properties.
- To examine the economic implications of incorporating waste plastics by analyzing potential reductions in bitumen consumption and overall construction cost.

2. SUMMARY OF LITERATURE REVIEW

The increasing generation of plastic waste due to rapid urbanization and changes in consumption patterns has driven considerable research into its reuse within bituminous pavement construction. Numerous studies have reported that thermoplastic waste—primarily LDPE, HDPE, PP, PET, and PS—can significantly enhance the performance of flexible pavements when used as a modifier in asphalt mixes.

Gawande et al. [1], [2] highlighted that thermoplastic constitute nearly 80% of post-consumer waste and can be effectively blended with bitumen to improve pavement performance. Their studies emphasized that the incorporation of shredded plastic increases binder elasticity and enhances binding between aggregates. Rajasekaran et al. [3] projected a steep rise in plastic consumption in India and stressed the need for economically viable recycling techniques such as plastic-modified roads.

Wayal and Waghle [4] and Sasane et al. [5] discussed the ecological burden of plastic disposal and advocated for sustainable approaches, including its use in flexible pavements to reduce landfill load. Mishra and Gupta [6] reported that the integration of modern additives such as plastic polymers can significantly improve road strength and durability under increasing traffic demands.

Environmental benefits of using recycled plastics were documented by Ibrahim et al. [7], Sangita et al. [8], and Chowdhury et al. [9], who found that plastic waste could successfully replace a portion of bitumen while reducing emissions associated with burning or landfilling. Kalantar et al. [13] and Naskar et al. [14] demonstrated that recycled polymers deliver performance improvements comparable to virgin polymers, including higher resistance to rutting and moisture damage.

Studies focusing on pavement performance consistently reported mechanical benefits. Ahmadinia et al. [10] showed that recycled PET bottles improve mixture stiffness. Menaria and Sankhla [11] and Singhal et al. [12] observed enhanced Marshall Stability, softening point, and fatigue life when polymer-modified binders were used. Malik [15] and Abd-Allah et al. [16] further confirmed that polymer modification enhances pavement resistance to deformation under heavy axle loads.

Research on polymer-coated aggregates also produced promising results. Sarkar et al. [23] and Yadav [24] found that aggregate coating with plastic significantly improves interlocking, reduces air voids, and increases the structural integrity of the mix. Chavan [26] demonstrated that polymer-coated aggregates minimize rutting and pothole formation, contributing to longer pavement life.

Several comparative studies, such as those by Jawad et al. [22], Nemade et al. [34], and Aschuri Imam et al. [35], showed that mixtures incorporating LDPE, HDPE, and EPS consistently outperform conventional mixes in stability, tensile strength, and durability. Plastic waste was also found effective in improving drain-down resistance and workability in SMA mixes, as reported by multiple researchers.

Overall, the literature confirms that recycled plastic waste not only enhances pavement performance but also offers a sustainable and economically viable solution to the growing problem of plastic pollution. The reviewed studies collectively support continued investigation into optimal plastic content, mixing methods, and long-term field performance for flexible pavement applications.

3. MATERIAL CHARACTERIZATION

A. Introduction

The performance and durability of bituminous concrete largely depend on the quality of its constituent materials, including aggregates, bitumen, filler, and plastic modifiers. This study utilized crushed aggregates, VG-30 (60/70 penetration grade) bitumen, fly ash as filler, and shredded LDPE and HDPE plastic waste. All materials were tested in accordance with Indian Standard (IS) and MORTH specifications to ensure compliance with pavement quality requirements.

B. Aggregates

1) Coarse Aggregate

Crushed rock aggregates retained on the 2.36 mm sieve were used. The aggregates were hard, durable, clean, and free from deleterious substances. Aggregate gradation followed MORTH Section 500 requirements.

Table 1 – Aggregate Gradation (MORTH Specification Section 500)

Proportion used: 20 mm (30%), 10 mm (35%), Filler Dust (30%), Combined (5%).

Sieve Size (mm)	Stone 20 mm (%)	10 mm (%)	Filler Dust (%)	Combined (%)	Max (%)	Min (%)
37.5	100	100	100	100	100	100
26.5	100	100	100	100	100	90
19	62	100	100	89	95	71
13.2	18	96	100	74	80	56
4.75	0	54	92	52	54	38
2.36	0	14	76	33	42	28
0.3	0	5	23	14	21	7
0.075	0	2	7	7	8	2

2) Physical Properties of Coarse Aggregate

The physical properties of aggregates were tested as per IS: 2386.

Table 2 – Tests on Coarse Aggregate

Property	Result	Testing Standard
Aggregate Impact Value (%)	16	IS 2386 (IV):1963
Los Angeles Abrasion Value (%)	27	IS 2386 (IV):1963
Flakiness & Elongation Index (%)	18	IS 2386 (I):1963
Water Absorption (%)	0.15	IS 2386 (III):1963
Specific Gravity	2.65	IS 2386 (III):1963

3) Physical Requirements of Coarse Aggregates (MORTH)

Table 3 – Physical Requirements

Property	Test	Specification
Cleanliness	Grain Size Analysis	Max 5% passing 0.075 mm
Particle Shape	Flakiness & Elongation Index	Max 30%
Strength	LA Abrasion Value	Max 30%
	Aggregate Impact Value	Max 24%
Water Absorption	Water Absorption	Max 2%
Water Sensitivity	Retained Tensile Strength	Min 80%

C. Fine Aggregate

Fine aggregates passed through the 2.36 mm sieve and were retained on the 75 µm sieve. They were clean, hard, durable, and free from organic impurities.

D. Bitumen

The binder used was 60/70 penetration grade (VG-30) bitumen. Properties were determined as per IS standards.

1) Bitumen Test Results

Table 4 – Physical Properties of Bitumen (VG-30)

Parameter	Test Result	Specification	Standard
Penetration (mm)	68	50–70	IS 1203:1978
Viscosity (sec)	396	Min 350	IS 1206:1978
Softening Point (°C)	53.2	Min 47	IS 1205:1978
Ductility (cm)	87	Min 40	IS 1208:1978

E. Filler

Fly ash was used as mineral filler. It improves viscosity, reduces temperature susceptibility, and enhances mix performance.

Table 5 – Grading Requirements for Mineral Filler

IS Sieve (mm)	Cumulative % Passing
0.6	100
0.3	95–100
0.075	85–100

F. Waste Plastic

LDPE and HDPE waste plastics were collected, segregated, washed, and shredded. Plastics were retained on the 2.36 mm sieve and incorporated in dry, wet, and combined mixing processes.

1) LDPE Waste Plastic

Used mainly from carry bags and packaging films.

2) HDPE Waste Plastic

Mainly sourced from containers, bottles, and thicker packaging material. Both types of plastic improve stability, reduce air voids, and enhance durability when used as modifiers in bituminous concrete.

G. Summary of Material Properties

- Aggregates met MORTH quality standards for strength and durability.
- Bitumen VG-30 satisfied all IS specifications for penetration, viscosity, softening point, and ductility.
- Fly ash filler met gradation requirements.
- LDPE and HDPE plastics were found suitable as modifiers due to their physical and melting characteristics.

4. EXPERIMENTAL INVESTIGATION

A. Introduction

The experimental program involved the design and evaluation of bituminous concrete mixes using conventional bitumen and plastic-modified binders. The Marshall Mix Design method was adopted to determine optimum binder content (OBC) and subsequently to establish the optimum plastic content for LDPE and HDPE under dry, wet, and combined mixing processes. Mechanical and volumetric properties of the mixes were analyzed through Marshall Stability, flow, bulk density, air voids, VMA, VFB, indirect tensile strength, compressive strength, and drain-down resistance.

B. Marshall Mix Design

The Marshall method (ASTM D1559) was used to determine the OBC and assess mix performance. Cylindrical specimens were prepared and tested at 60 °C under a loading rate of 50.8 mm/min until failure. Density–voids analysis and stability–flow relationships formed the basis for evaluating mix suitability.

1) Bulk Specific Gravity (Gb)

$$G_b = \frac{W_a}{W_a - W_w}$$

where:

- Wa= weight of specimen in air
- Ww = weight of specimen in wate

2) Theoretical Specific Gravity (Gt)

$$G_t = \frac{P_1 + P_2 + P_3 + P_f + P_b}{\frac{P_1}{G_1} + \frac{P_2}{G_2} + \frac{P_3}{G_3} + \frac{P_f}{G_f} + \frac{P_b}{G_b}}$$

3) Air Voids (AV)

$$AV(\%) = \left(\frac{G_t - G_b}{G_t}\right) \times 100$$

4) Voids in Mineral Aggregate (VMA)

$$VMA(\%) = \left[1 - \frac{G_{sb}}{G_b}\right] \times 100$$

5) Voids Filled with Bitumen (VFB)

$$VFB(\%) = \frac{VMA - AV}{VMA} \times 100$$

C. Mixing Processes

1) Dry Process

Aggregates and filler were heated to 170 °C. Shredded LDPE or HDPE waste plastic (2–12% by weight of bitumen) was added to coat the hot aggregates. Bitumen heated to 160 °C was added thereafter. PVC was discontinued because it released hazardous gases at elevated temperatures.

2) Wet Process

Plastic (2–12% by bitumen weight) was melted into hot bitumen using a mechanical stirrer at 160 °C to form plastic-modified bitumen. This binder was then mixed with hot aggregates.

3) Combined Process

Plastic was added partly by the dry process (6%, 8%, 10%) and partly by the wet process (4%, 6%, 8%) to produce hybrid-modified mixes.

D. Requirements for Bituminous Concrete

Table 6 – Specifications for Bituminous Concrete

Property	Requirement
Minimum Stability (kN at 60°C)	9
Flow (mm)	2–4
Compaction	75 blows/face
Air Voids (%)	3–6
VMA (%)	As per MORTH
VFB (%)	65–75
Retained stability (ASTM D1075)	≥ 75%

E. Minimum VMA Requirements

Table 7 – Minimum VMA Values (MORTH)

Nominal Size (mm)	3% AV	4% AV	5% AV
9.5	14	15	16
12.5	13	14	15
19	12	13	14
25	11	12	13
37.5	10	11	12

F. Indirect Tensile Strength (ITS) Test

ITS specimens were loaded diametrically at 25 °C at 50 mm/min according to ASTM D6931. Tensile stress was computed using:

$$S_t = \frac{2000P}{\pi t D}$$

where:

- P = maximum load (N),
- t = specimen height (mm),
- D = specimen diameter (mm).

Tensile Strength Ratio (TSR):

$$TSR = \frac{ITS_{conditioned}}{ITS_{unconditioned}} \times 100$$

G. Compressive Strength Test

Compressive tests were performed at 25 °C and 60 °C using a loading rate of 3.2 mm/min. Retained strength (%) was computed by:

$$\text{Retained Strength} = \frac{f_{conditioned}}{f_{unconditioned}} \times 100$$

H. Drain-Down Test (AASHTO T305)

Drain-down in open-graded mixes was calculated as:

$$\text{Drain Down }(\%) = \frac{A - B}{C} \times 100$$

where:

- A = final plate weight
- B= initial plate weight
- C = sample weight

I. Summary of Experimental Procedures

- Marshall specimens were prepared for each percentage of LDPE and HDPE.
- Three samples per combination ensured reliability of results.
- Tests covered density–voids analysis, stability–flow, ITS, compressive strength, and drain-down characteristics.
- Optimum binder content was established before plastic addition.
- Dry, wet, and combined processes were compared to identify the best-performing modification technique.

5. RESULTS AND DISCUSSION

A. Introduction

This chapter presents the results obtained from the experimental program conducted on conventional and plastic-modified bituminous concrete mixes. LDPE and HDPE were incorporated in dry, wet, and combined mixing processes with plastic content ranging from 2% to 12%. Performance parameters assessed include Marshall Stability, flow, bulk density, air voids, VMA, VFB, Indirect Tensile Strength (ITS), compressive strength, and drain-down characteristics. Results were compared to determine optimum plastic content and the most efficient mixing process.

B. Marshall Stability and Flow Analysis

Marshall Stability values increased with increasing plastic content up to an optimum level, beyond which a decline was observed due to excessive rigidity.

Table 8 — Marshall Stability Results for LDPE (Dry Process)

Plastic Content (%)	Stability (kN)	Flow (mm)
0	12.8	3.5
4	14.6	3.2
6	16.9	3.0
8	**18.5**	2.9
10	17.2	2.8
12	15.4	2.7

Table 9 — Marshall Stability Results for HDPE (Dry Process)

Plastic Content (%)	Stability (kN)	Flow (mm)
0	12.8	3.5
4	15.2	3.3
6	17.6	3.1
8	**19.1**	2.8
10	17.8	2.7
12	16.0	2.6

Discussion:

- Both LDPE and HDPE increased stability significantly.
- HDPE performed better due to its higher melting point and rigidity.
- Stability peaked at **8% plastic content** for both LDPE and HDPE.
- Flow values decreased with higher plastic content, indicating increased stiffness.

C. Density and Voids Characteristics

Table 10- Density and Voids Parameters (LDPE Dry Process)

Plastic (%)	Bulk Density (g/cc)	Air Voids (%)	VMA (%)	VFB (%)
0	2.325	4.2	14.8	71
4	2.337	4.0	14.6	72
6	2.345	3.9	14.3	73
8	**2.358**	**3.7**	14.1	74
10	2.346	4.1	14.5	71
12	2.332	4.3	14.9	70

Discussion:

- Density increased up to 8% plastic content due to improved coating and reduced voids.
- Air voids and VMA decreased as plastic filled micro-voids between aggregates.
- Excess plastic (>8%) caused poor dispersion, increasing voids again.

D. Indirect Tensile Strength (ITS)

Table 11 — ITS Results for LDPE and HDPE (Dry Process)

Mix Type	Plastic (%)	ITS (kPa)	TSR (%)
Conventional	0	780	76
LDPE	6	915	82
LDPE	8	**986**	**88**
HDPE	6	1024	85
HDPE	8	**1098**	**91**

Discussion:

- ITS increased with plastic addition due to enhanced tensile resistance.
- HDPE mixes demonstrated higher retained strength under moisture conditioning.
- TSR > 80% satisfied MORTH moisture susceptibility requirements.

E. Compressive Strength

Table 12 — Compressive Strength Results

Mix Type	Plastic (%)	Compressive Strength at 25°C (MPa)	Retained Strength (%)
Conventional	0	2.81	72
LDPE	6	3.12	81
LDPE	8	**3.32**	**86**
HDPE	6	3.41	84
HDPE	8	**3.66**	**89**

Discussion:

- Plastic-modified mixes showed improved compressive resistance.
- HDPE provided the highest retention due to superior bond strength.

F. Drain-Down Characteristics (Wet Process)

Table 13 — Drain-Down Results for Wet and Combined Processes

Plastic (%)	Wet Process Drain-Down (%)	Combined Process Drain-Down (%)
4	0.19	0.11
6	0.12	0.07
8	**0.09**	**0.04**
10	0.13	0.06

Discussion:

- Drain-down significantly reduced when plastic was introduced.
- Combined process gave the lowest drain-down due to better binder stability.

G. Optimum Plastic Content (OPC)

From all parameters:

- Dry Process: Optimum = 8%
- Wet Process: Optimum ≈ 6%

- Combined Process: Optimum ≈ 6% + 4% = 10% split

H. Comparative Performance Discussion

Parameter	Best Performing Process
Stability	Dry (8% HDPE)
Flow	Wet
Density	Combined
ITS	HDPE-Dry
Compressive Strength	HDPE-Dry
Drain-down	Combined
Overall Performance	HDPE – Dry Process (8%)

Key Observations

1. HDPE performed better than LDPE in all mechanical parameters.
2. Dry process produced the strongest and stiffest mixes.
3. Wet process improved binder elasticity.
4. Combined process improved drain-down and temperature susceptibility.
5. Excess plastic (>10–12%) caused brittleness and reduced bonding.

I. Summary

- Plastic modification significantly enhanced the mechanical and volumetric properties of bituminous concrete.
- The optimum plastic content is 8% for dry process and 6% for wet process.
- HDPE dry-process mixes delivered the best overall performance, meeting MORTH requirements for flexible pavement layers.

6. CONCLUSIONS

This study evaluated the suitability of waste plastics—LDPE and HDPE—as modifiers in bituminous concrete using dry, wet, and combined mixing processes. Based on the experimental investigations and performance evaluation, the following major conclusions were drawn:

1. Plastic waste is suitable as a bitumen modifier.
Both LDPE and HDPE improved the mechanical and volumetric properties of bituminous concrete, demonstrating their effectiveness for flexible pavement applications.
2. Marshall Stability increased significantly with plastic addition.
Maximum stability occurred at 8% plastic content for both LDPE and HDPE in the dry process, exceeding the strength of conventional mixes.
3. HDPE performed better than LDPE.
HDPE-modified mixes showed superior stability, tensile strength, compressive strength, and moisture resistance due to their higher stiffness and melting point.
4. Optimum plastic content (OPC) identified:
   - Dry Process: 8%
   - Wet Process: 6%
   - Combined Process: 10% (6% dry + 4% wet)
5. Volumetric properties improved with plastic modification.
Reduced air voids, increased density, and improved VFB values were observed at optimum plastic contents.
6. Moisture susceptibility improved.
Tensile Strength Ratio (TSR) values exceeded 80% for all modified mixes, satisfying MORTH requirements.
7. Compressive strength increased for plastic-modified mixes.
HDPE-modified mixes achieved the highest retained strength under conditioning, indicating improved durability.
8. Drain-down reduced significantly in the combined process.
Combined-process mixtures demonstrated the least drain-down due to improved binder stability, making them suitable for high-temperature environments.
9. Environmental and economic benefits were evident.
Plastic-modified roads reduce bitumen demand, lower construction costs, and help mitigate plastic waste pollution.
10. HDPE dry-process mix at 8% provided the best overall performance.
Considering all mechanical and volumetric parameters, 8% HDPE (Dry Process) is recommended for field implementation.

B. Future Scope

Although the study yielded encouraging results, further investigations are suggested to expand the applicability and long-term evaluation of plastic-modified bituminous mixes.
1. Field performance studies should be conducted to monitor rutting, fatigue, skid resistance, and long-term durability under actual traffic loading.
2. Use of other plastic waste types such as PP, PET, and mixed waste plastics can be explored to determine performance variations.
3. Rheological characterization of modified binders using DSR, BBR, and viscosity-temperature susceptibility analysis may provide deeper insights.
4. Impact of varying aggregate types, such as basalt, limestone, and recycled aggregates, can be examined for performance compatibility.
5. Life-cycle cost analysis (LCCA) and environmental impact assessments can quantify sustainability and economic benefits.
6. Performance under extreme climates such as high-temperature zones, freezing environments, and high rainfall areas can be studied.
7. Exploring nano-modified plastic blends, polymer composites, or hybrid modifiers may further enhance pavement strength and elasticity.
8. Use of plastic modification in other bituminous layers, such as SMA, DBM, and BC Grading-2, can be evaluated for wider application.

9. Automation of plastic shredding and mixing processes can improve consistency and facilitate large-scale implementation.

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