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Sustainable Roads: Evaluating Plastic-Modified Bitumen for Performance & Cost

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Abstract
India generated about 4.13 million tonnes of plastic waste in financial year 2022–23, while the Ministry of Rural Development reported 43,700 km of road works using waste plastic completed under PMGSY by 31 July 2025. This paper reviews published evidence on pavement performance, cost, and environmental considerations, focusing on Indian bituminous roads and using one Pakistan study for context. The sources examine different approaches: the IRC dry process, PET used to replace part of the bitumen in a laboratory mix, and partial replacement of mineral aggregate. Their results are not directly interchangeable. Laboratory studies and Indian field evaluations report favourable results for some performance measures, but they cover different materials, roads and test conditions. One laboratory study reported a 5.18% material-mix cost reduction; a separate PMGSY assessment estimated a 4.3% lifecycle-cost reduction under its own assumptions. The same government assessment reported slightly higher construction-stage embodied energy and carbon for waste-plastic roads. A recent laboratory study has also proposed a way to measure possible microplastic release, although it does not establish release rates from roads in service. The evidence supports careful, quality-controlled use in the settings studied, not a universal claim that these roads are more durable, cheaper, or environmentally preferable.

I. Introduction

Plastic waste and damaged road surfaces are both familiar public concerns in Delhi NCR and other Indian cities, although they are not the same problem. Using suitable waste plastic in road construction may give some difficult-to-recycle material another use. Whether this is a sound engineering choice depends on what the road and environmental evidence actually show, rather than on the appeal of the idea alone.

A written reply to the Rajya Sabha reported that India generated about 4.13 million tonnes of plastic waste in 2022–23, based on information supplied by State Pollution Control Boards and Pollution Control Committees to the Central Pollution Control Board (Ministry of Environment, Forest and Climate Change [MoEFCC], 2025). Under the Pradhan Mantri Gram Sadak Yojana (PMGSY), the Ministry of Rural Development reported that 43,700 km of road works using waste plastic had been completed out of 56,875 km sanctioned by 31 July 2025. The programme calls for waste plastic to be used in at least 70% of the eligible proposed road length involving the hot-mix process; this is not a requirement for 70% of all rural roads (Ministry of Rural Development [MoRD], 2025). These numbers show substantial adoption, but adoption alone does not prove technical or environmental superiority.

The studies do not examine one uniform technology. In the Indian Roads Congress (IRC) dry process, selected shredded plastic is added to heated aggregate before bitumen. Other studies use plastic to replace a share of the binder, while another route replaces some mineral aggregate. Each changes a different part of the mixture, so results should be interpreted separately (IRC, 2013, 2020; Sasidharan et al., 2019; Usama & Hafeez, 2024).

An earlier review noted that reliable maintenance evidence was limited at the time (Sasidharan et al., 2019). Later field studies and government assessments add to that record, though questions remain about long-term performance, full cost, and environmental effects. This paper asks: What does the published evidence from India suggest about pavement performance and cost-effectiveness when waste plastic is used in bituminous roads, and what environmental or methodological uncertainties remain?

II. Methodology

This paper is a narrative literature review, not a primary experiment or an exhaustive systematic review. It draws on the source set assembled for this study: peer-reviewed laboratory and field papers, two literature reviews, IRC technical guidance, PMGSY and NRIDA documents, a pavement-distress manual, an official parliamentary reply on plastic-waste generation, and recent research on possible microplastic release. The materials consulted include scholarly search and publisher pages such as Google Scholar and ScienceDirect, as well as official government repositories. A complete dated search log and a count of all screened records were not retained, so the search cannot be reproduced as a systematic review.

Sources were retained when they addressed at least one of four questions: how the plastic was incorporated; what mixture or road-performance measures were reported; how costs were calculated; or what

environmental and implementation limits were identified. For each study, the review considered its setting, mixture or road type, plastic route and dosage basis where reported, comparator, main result and stated limitations. Different outcome measures were not combined into a single score. Standards were used to describe technical requirements, not as evidence that a road performs better in service; government press releases were treated as summaries rather than substitutes for the underlying data.

2.1 Technical standards and incorporation routes

IRC:SP:98-2013 gives a waste-plastic dosage of 6–8% by weight of bitumen for its applicable dry-process mixes, depending on the conditions specified in the guideline. Its permitted-material clause lists low-density polyethylene (LDPE), high-density polyethylene (HDPE), polyethylene terephthalate (PET), and polyurethane (PU). The first revision, IRC:SP:98-2020, specifies 8% bitumen by weight for its prescribed applications and limits the listed feedstock to LDPE and HDPE. Both editions exclude black-coloured plastic and polyvinyl chloride (PVC); the guidance warns about the risks of repeated recycling of black-coloured waste and the hazardous emissions that can result from heating PVC. The 2020 guidance also stresses temperature control (IRC, 2013, 2020).

The mixture thresholds also differ by edition. For the stated dense-graded mixes, the 2013 guideline lists Marshall stability of at least 12 kN at 60°C, flow of 2–4 mm, air voids of 3–5%, a voids-in-mineral-aggregate (VMA) minimum of 16%, and retained Marshall stability of 98%. The 2020 revision specifies the same stability, flow, and air-void ranges, a VMA minimum of 15%, and retained Marshall stability of at least 90% or a tensile-strength ratio of at least 90%. These values belong to their own editions and mix requirements; they should not be combined into a single universal specification. The Ministry of Rural Development's 2025 summary refers to IRC:SP:98-2013, so this review does not assume that every project used the same edition (IRC, 2013, 2020; MoRD, 2025).

The Federal Highway Administration's Distress Identification Manual is used here only to help describe pavement distress. It is not an Indian PCI standard and does not establish whether plastic-modified pavement performs better (Miller & Bellinger, 2014).

III. Findings

Laboratory evidence on mixture performance

Vasudevan et al. (2012) examined plastic-coated aggregate, an early approach related to the Indian dry process. The study tested formulations using polyethylene (PE), polypropylene (PP) and polystyrene (PS), and reported favourable aggregate properties and higher Marshall stability in selected mixtures. Because this work predates IRC:SP:98-2013, the polymers tested should not be treated as the same list as the feedstocks prescribed in later IRC guidance. Its findings apply to the formulations tested, not to every polymer or road mix.

Hake et al. (2020) tested semi-dense bituminous concrete (SDBC) mixtures in which shredded PET replaced 5%, 7.5%, 10%, 12.5% and 15% of the bitumen by weight. The highest Marshall stability was reported at 10% PET, at 1.6% above the conventional mixture; the study gave an optimum bitumen content of 5.25%. This was a laboratory formulation in which PET replaced part of the binder, not the IRC dry process in which plastic coats heated aggregate. The authors called for further investigation and field-performance assessment (Hake et al., 2020).

Singh and Gupta (2024) reviewed laboratory and field research on the dry process. Across the studies they examined, many mixtures performed better on measures such as stability, rutting resistance, fatigue behaviour or moisture susceptibility, although results varied with plastic type, mix design and test conditions. Their review helps place individual studies in context, but it is a synthesis of heterogeneous work rather than a new experiment or proof that all dry-process mixtures perform better.

Evidence from Indian roads in service

Biswas et al. (2020) compared five plastic-modified road sections with five conventional sections in Pune. Their assessment included field distress surveys, Benkelman Beam Deflection, surface roughness, and skid-resistance tests. The authors used the Analytic Hierarchy Process (AHP), with weights assigned by transportation professionals, to rank distress parameters. The paper reports PCI and deterioration rankings as separate assessment results; the AHP rankings should not be described as creating the PCI. The authors found slower deterioration in the plastic-modified sections. However, the study covers only ten sections in one city, and the dosage denominator is not clear enough in the accessible article text to compare the reported amount numerically with the IRC guideline (Biswas et al., 2020).

A PMGSY performance evaluation by seven institutes under the supervision of the Indian Institute of Technology Madras reported lower levels of ravelling, cracking and potholes, along with higher Pavement Condition Index (PCI) ratings, on the evaluated waste-plastic roads. The NRIDA annual report also describes mostly lower measured roughness for waste-plastic roads on routes carrying up to 100 commercial vehicles per

day. Its service-life analysis estimated that the PCI threshold used in the assessment could be reached about 1–1.5 years later, allowing routine maintenance to be deferred by around one year on average (NRIDA, 2023; MoRD, 2025). These findings add field evidence, but the public summaries do not provide every detail needed to reproduce the assessment independently.

For international context, Usama and Hafeez (2024) evaluated a road in Pakistan where waste plastic partially replaced mineral aggregate. They reported an International Roughness Index (IRI) of 2,200 mm/km, described as within the applicable limit, and better skid resistance than the virgin-asphalt control. The paper also reports British Pendulum surface-friction values below 65. These relative results should be read with that qualification rather than taken as proof that the surface meets every safety criterion under all conditions. Since plastic replaced aggregate rather than being incorporated through the Indian dry process, the study is not a like-for-like comparison with the Indian evidence.

Cost-Effectiveness

The available cost figures describe different things. Hake et al. (2020) reported a 5.18% reduction in the material-mix cost for the PET-modified laboratory formulation they studied. The PMGSY assessment reported a 4.3% reduction in lifecycle cost under its own road-life, traffic and maintenance assumptions; the ministry's 2025 summary describes the reduction as marginal (MoRD, 2022, 2025; NRIDA, 2023). These estimates should not be combined into one range or converted into a general cost-per-kilometre claim.

A fuller economic comparison would need consistent accounting for collection, sorting, cleaning, shredding, transport, plant controls, materials, construction, maintenance and rehabilitation. The reviewed sources identify processing and sorting as practical challenges, but they do not provide a sufficiently consistent dataset to assign a general cost premium to these steps (Sasidharan et al., 2019). The evidence therefore does not establish that waste-plastic roads are always cheaper over their full service life.

Environmental and implementation considerations

The possible benefit of putting plastic into roads depends partly on feedstock quality and control at the mixing plant. IRC guidance excludes PVC and black-coloured waste from the prescribed dry process and, in the 2020 edition, lists LDPE and HDPE for the specified applications. It also warns that unsuitable plastics or excessive heating can create hazardous emissions. Collection, sorting and temperature control therefore matter to both material consistency and worker and environmental protection; mixed waste plastic should not be treated as a uniform material (IRC, 2013, 2020; Sasidharan et al., 2019).

The PMGSY comparison also cautions against assuming that waste-plastic roads automatically have a lower environmental footprint. The Vision Document's construction-stage comparison reported embodied energy and embodied carbon marginally higher for waste-plastic roads, by up to about 2%, than for conventional roads. This is a construction-stage comparison, not a complete lifecycle assessment of every environmental effect, so possible waste-diversion benefits need to be considered alongside those inputs (MoRD, 2022).

A study published in October 2026 examined possible microplastic release from recycled-plastic-modified asphalt under laboratory conditions. Liu et al. (2026) used Laser Direct Infrared (LDIR) imaging and proposed a normalized particle area (NPA) index. After combined high-temperature and moisture conditioning, the modified mixture had an apparent NPA 56.5% lower than the unmodified asphalt in their test. This is not a finding that roads in service release 56.5% fewer confirmed plastic particles. The authors also detected LDPE-like signals in the asphalt binder itself, making it difficult to attribute every signal to added recycled plastic. NPA should therefore be treated as a preliminary laboratory indicator, not a field release rate or proof that release is absent or environmentally safe under traffic and weathering (Liu et al., 2026).

Table 1 summarises the principal sources, their incorporation routes, main contributions, and key limitations.

Table 1. Principal sources, incorporation routes, findings and limitations:

Source/setting	Method and dosage basis	Main contribution	Main limitation
IRC:SP:98 (2013, 2020)	Technical guidance for the dry process; 6–8% by weight of bitumen in applicable 2013 mixes and 8% in the 2020 revision.	Defines eligible feedstocks, processing precautions and mixture requirements for the stated editions.	A specification describes practice; it does not prove better performance or lower cost in service.

Source/setting	Method and dosage basis	Main contribution	Main limitation
Sasidharan et al. (2019)	Review of waste-plastic use in road construction, including dry and wet processes.	Summarises earlier Indian experience and practical concerns such as sorting and PVC-related risks.	A historical review; its maintenance-evidence discussion predates later PMGSY evaluations.
Vasudevan et al. (2012), India	Laboratory and early field work on plastic-coated aggregate; formulations included PE, PP and PS.	Reported favourable aggregate properties and mixture stability for selected formulations.	Predates the IRC guidance; results from selected formulations should not be generalised to every polymer or road.
Hake et al. (2020), India	Laboratory SDBC mix in which PET replaced 5–15% of the bitumen by weight.	Reported an optimum at 10% PET, with Marshall stability 1.6% above the conventional mix, and a 5.18% material-mix cost reduction.	A particular laboratory formulation; it is not the IRC dry process and does not establish whole-road or lifecycle savings.
Biswas et al. (2020), Pune	Five plastic-modified and five conventional road sections; field distress, deflection, roughness, and skid-resistance assessments.	Reported slower deterioration in the plastic-modified sections; AHP was used to rank distress parameters.	A small, single-city sample. The dosage denominator is not clear in the accessible source text; AHP ranking and PCI calculation should not be conflated.
Singh and Gupta (2024)	Review of laboratory and field studies of the dry process.	Found generally favourable trends in several pavement measures while noting variation across materials and test conditions.	Synthesises heterogeneous studies rather than reporting one new experiment.
NRIDA / MoRD, PMGSY	Programme-level assessment of rural roads built with waste plastic under the relevant project guidance.	Reports lower surface distress, higher PCI, about one-year maintenance deferral and a 4.3% lifecycle-cost reduction under the assessment assumptions.	Public summaries do not expose every dataset or assumption; the cost figure is not a universal saving.
Usama and Hafeez (2024), Pakistan	Road evaluation using plastic for partial mineral-aggregate replacement, rather than the Indian dry process.	Reported IRI of 2,200 mm/km within the stated limit and better skid resistance than the control.	A different incorporation route; the authors also reported British Pendulum values below 65. It is supporting context, not a like-for-like comparison.
Liu et al. (2026), laboratory	LDIR imaging and a normalized particle area (NPA) index after combined heat and moisture conditioning.	The modified mix had an apparent NPA 56.5% lower than the unmodified asphalt under the study conditions.	A preliminary laboratory indicator: LDPE-like signals in native asphalt complicate attribution, and field release rates remain unknown.

IV. Discussion

The evidence is encouraging in some respects, but it is not uniform. Laboratory studies report favourable properties for selected mixtures; the Pune comparison reports slower deterioration on the sections studied; and the PMGSY assessment reports improved surface-condition measures and later maintenance needs for the rural roads it evaluated. These findings support continued, quality-controlled use and evaluation of the dry process in contexts similar to those studied. They do not show that every plastic type, mixture or road will achieve the same result.

The cost evidence needs the same care. Hake et al.'s 5.18% figure is a material-mix estimate for one laboratory formulation, while the 4.3% PMGSY figure is a lifecycle estimate based on programme assumptions. Neither should be treated as a guaranteed saving. The government assessment also reported somewhat higher construction-stage embodied energy and carbon, and the 2026 microplastic study shows that environmental measurement and source attribution remain difficult. Technical specifications and a large deployment total are useful context, but neither resolves these open questions by itself.

V. Limitations and Future Research

This review is non-exhaustive. It does not include a complete search log, a formal risk-of-bias assessment or a statistical synthesis. The studies use different methods and outcome measures; the Pune field comparison covers ten sections in one city; some programme-level findings are available only through summary documents; and the international case uses a different incorporation route. The cost estimates also use different boundaries.

Further work would benefit from following matched road sections over several years, documenting the actual plastic content in the finished mix, reporting construction and maintenance costs on a consistent basis, and comparing environmental outcomes within clearly defined system boundaries. Laboratory microplastic tests should also be checked against field measurements under traffic and weathering. These steps would help show where the method is useful without assuming in advance that it is always preferable

VI. Conclusion

Published evidence provides a reasonable basis for the continued, carefully controlled use and evaluation of waste plastic in bituminous roads in India, but not for a universal claim of superior performance. Laboratory studies have reported favorable results for selected plastic-coated-aggregate and PET-substituted mixtures, while Indian field evaluations have reported better surface-condition outcomes for some roads. The PMGSY Vision Document also reported lifecycle-cost reductions under its assessment assumptions. However, the evidence is still limited by differences in incorporation methods, small field samples, incomplete cost comparisons, and unresolved environmental questions.

The most defensible conclusion is that waste-plastic incorporation is a potentially useful road-construction approach, with success depending on the method, materials, quality control, and conditions of use. It may help use selected plastic waste and improve pavement performance in some settings. Long-term independently verifiable performance, whole-life costs, and environmental outcomes still require further evidence.

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