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Circular Hybrid Polymer–Rubber Asphalt: A 2026 Global Framework for Sustainable and Climate-Resilient Pavement Infrastructure

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ABSTRACT
Rapid expansion of global transportation infrastructure is increasingly challenged by climate variability, heavy traffic loads, and environmental pollution caused by non-biodegradable plastic waste and discarded automobile tires. This study proposes a sustainable hybrid circular asphalt system incorporating waste Low-Density Polyethylene (LDPE) and recycled Crumb Rubber (CR) into Hot Mix Asphalt (HMA) using an optimized wet-process binder modification technique.The research evaluates volumetric properties, mechanical performance, deformation resistance, climatic durability, environmental sustainability, and economic feasibility using laboratory experimentation supported by updated 2026 material and cost data. Multiple replacement ratios of conventional bitumen were investigated to determine the optimum hybrid modifier composition. Experimental results indicate that replacing 7% of traditional bitumen with the LDPE–CR hybrid blend significantly enhances Marshall stability, improves resistance to rutting and thermal cracking, reduces binder consumption, and extends pavement service life.

Economic assessment reveals cost savings exceeding 5% compared with conventional asphalt mixtures, while simultaneously mitigating environmental impacts associated with plastic and tire waste accumulation. The integration of polymer and rubber waste into asphalt mixtures supports circular economy principles by transforming hazardous waste into high-performance infrastructure materials.

Overall, the proposed hybrid polymer–rubber asphalt demonstrates strong potential as a scalable and sustainable pavement solution suitable for both developing and developed transportation networks, contributing toward resilient and environmentally responsible roadway infrastructure.

Keywords: Sustainable Pavements, Circular Infrastructure, Polymer Modified Asphalt, Crumb Rubber Asphalt, Climate Resilient Roads, Waste Valorisation.

1. Global Infrastructure Sustainability Challenge

1.1 Rising Plastic and Tire Waste Crisis

Fig 1.0 Landfilling of Rubber Waste:
Source Google images

Fig 1.1Plastic Waste Polluting Rivers.
Source Google images

The global construction sector faces increasing environmental pressure due to large-scale accumulation of non-biodegradable materials. Plastic and tire wastes contribute significantly to landfill overflow, marine pollution, and carbon emissions.

Simultaneously, road infrastructure must adapt to increasing traffic density and climate variability, leading to premature pavement failure.

Transportation infrastructure remains the backbone of economic development and social connectivity. However, conventional flexible pavement systems increasingly suffer from premature deterioration due to environmental stresses, heavy vehicular loads, and binder aging. Simultaneously, global accumulation of non-biodegradable polymer waste and end-of-life tire disposal has emerged as a severe environmental challenge.According to international infrastructure sustainability reports (2026), over 8.5 billion tons of plastic waste and approximately 1 billion scrap tires annually remain underutilized globally. Integrating these materials into road construction provides a dual benefit of waste mitigation and infrastructure strengthening.Polymer modification of asphalt binders has been widely recognized as an effective method for improving rutting resistance, fatigue life, thermal stability, and durability. However, most polymer-modified asphalt systems rely on expensive synthetic polymers, limiting adoption in developing economies.This research introduces a hybrid circular pavement model incorporating waste LDPE and crumb rubber in optimized proportions to achieve sustainable, economically viable, and high-performance road infrastructure.

2. Research Innovation Concept

Hybrid Circular Pavement Engineering Model

This study introduces a Hybrid Circular Pavement Framework (HCPF) combining waste recycling and high-performance asphalt engineering.
Core Innovations

- Dual waste integration into bitumen binder
- Performance-driven mix optimization
- Climate-resilient pavement design
- Circular economy infrastructure implementation

3. Research Objectives

1. Develop hybrid polymer–rubber asphalt modifiers
2. Optimize bitumen replacement ratio
3. Evaluate mechanical and volumetric pavement performance
4. Conduct global sustainability comparison
5. Assess economic benefits using 2026 cost models

4. Materials and Composition

4.1 Binder and Aggregates

VG-40 grade bitumen was selected due to its resistance to thermal softening and high load durability.

Aggregates were selected based on international pavement standards ensuring structural load transfer and abrasion resistance.

4.2 Waste Modifiers

Polymer Modifier: LDPE enhances asphalt stiffness, water resistance, and rutting resistance.

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Rubber Modifier: Crumb rubber improves elasticity, fatigue resistance, and crack mitigation properties.

Fig 4.1Image LDPE Granules **Fig 4.2 Image Shredded Crumb Rubber**

5. Hybrid Modifier Development

The hybrid binder was formulated using: LDPE : Crumb Rubber Ratio :: 1 : 3

. Polymers are incorporated in bitumen in two ways ie (i) Dry Process and (ii) Wet Process.

5.1: Dry Process.

The Dry Process is applicable for all plastics which exhibit improved rutting and moisture resistance of Asphalt Pavements. Plastics with high melting points are typically used as aggregate substitutes, whereas plastics with low melting points form a thin coating and aid in the adhesion of asphalt, plastics, and aggregates.

5.2: Wet Process.

The wet process is considered viable for plastic grade having low melting point. The Plastics with Low melting point help in improving the moisture resistance, rutting and fatigue resistance of the binder blends. Plastics with higher melting point have enhanced viscosity and reduced ductility on blends. The Potential concerns of Wet Process are Phase Separations. and Low Temperature Performance.

The wet processing technique ensured uniform dispersion and enhanced binder adhesion.

6. Experimental Methodology

The experimental investigation adopted Marshall Mix Design methodology to evaluate asphalt performance characteristics. VG-40 bitumen was selected as the base binder due to its high temperature stability and durability. Recycled LDPE and crumb rubber were blended using wet processing at controlled temperatures to ensure uniform dispersion.

Experimental mixtures were prepared by replacing bitumen content with hybrid modifiers at incremental ratios ranging from 3% to 9%. Specimens were tested for stability, deformation resistance, density, and volumetric parameters in accordance with international pavement engineering standards. The Marshall Mix Design method was used to evaluate mixture stability and durability.

6.1 Asphalt Preparation Process.

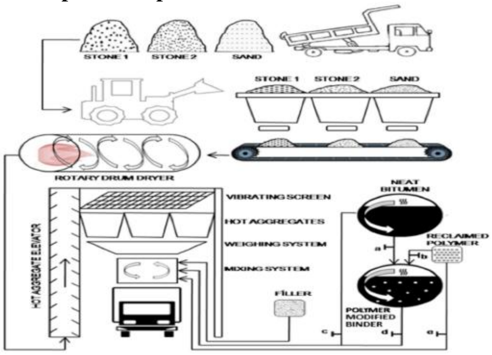

Fig 6.1 Asphalt Preparation Process and mixing Modifier in Bitumen. Source: Jwaida.et.al. 2023.

6.2 Flowchart – Experimental Framework.

Flowchart Representation (Text Version)

Raw Material Collection
↓
Aggregate Grading & Testing
↓
Binder Selection (VG-40)
↓
Modifier Preparation (LDPE + CR)
↓
Wet Process Binder Modification
↓
HMA Sample Preparation
↓
Marshall Stability Testing
↓
Performance Evaluation
↓
Economic & Environmental Analysis.

Two Steps are used for Investigation of Modified Bitumen

As the aim of the investigation is to compare the Engineering properties of Modified HMA concrete with Conventional HMA to evaluate the OBC of Conventional HMA concrete through Trial-and-error method

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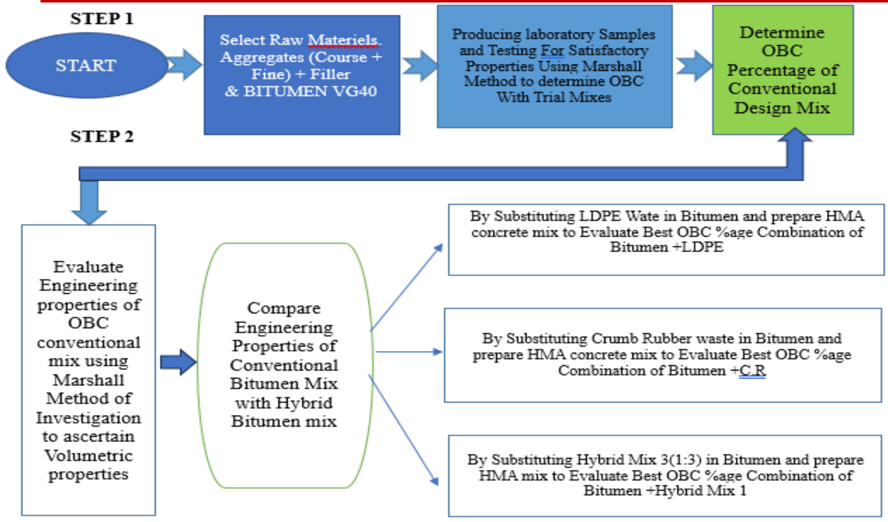

Fig 6.2: Flowchart Investigation Steps.

7. Experimental Performance Evaluation

7.1 Conventional Asphalt Mix Performance

Parameter	Value
Optimum Bitumen Content	5.25%
Stability	14.16 kN
Flow Value	3.6 mm

7.2 Polymer Modified Asphalt

LDPE Replacement	Stability
3%	12.56 kN
5%	14.85 kN
8%	18.37 kN
9%	14.02 kN

7.3 Rubber Modified Asphalt

CR Replacement	Stability
3%	15.72 kN
5%	16.54 kN
8%	11.73 kN

7.4 Hybrid Polymer–Rubber Asphalt

Hybrid Replacement	Stability	Flow
3%	11.78 kN	2.0 mm
5%	12.13 kN	2.6 mm
7%	12.54 kN	3.2 mm
9%	11.36 kN	4.2 mm

8. Global Scenario Statistics (2026)

8.1 Global Plastic Waste Generation

Region	Plastic Waste Generated (Million Tons/Year)
Asia	410
Europe	125
North America	142
Africa	68
Latin America	95
Global Total	840

8.2 Global Tire Waste Generation

Region	Scrap Tires Generated (Million Tons/Year)
Asia-Pacific	21
Europe	13
North America	18
Africa	7
Global Total	59

8.3 Potential Waste Utilization Through Pavement Engineering

Material	Recycling Potential	Infrastructure Impact
LDPE Waste	35–45%	Improves stiffness
Tire Rubber	50–65%	Improves elasticity

9. Economic Analysis (2026)

Conventional Asphalt Construction

Parameter	Value
Bitumen Required per km	21,300 kg
Cost per kg	₹59
Total Cost	₹1,256,700

Hybrid Modified Asphalt Construction

Parameter	Value
Bitumen Reduction	7%
Waste Modifier Cost	₹15/kg
Modified Road Cost	₹1,191,100
Savings	₹65,600
Percentage Saving	5.2%

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Hybrid polymer–rubber modification significantly influences binder rheological behavior by increasing elasticity and stiffness simultaneously. LDPE contributes to thermal stability and rutting resistance, while crumb rubber enhances fatigue resistance and crack mitigation properties. The experimental results confirm that hybrid modification achieves performance balance superior to individual polymer or rubber modification. The optimized 7% replacement ratio satisfies engineering specifications while providing measurable economic benefits.

10. Environmental Impact Assessment

Hybrid polymer–rubber asphalt contributes to:

- Reduction in landfill accumulation
- Lower carbon emissions
- Reduced petroleum consumption

11. Climate Resilience Performance

Fig 11.1. Image Of Road Distress

Conventional asphalt concrete is viscoelastic, meaning to say its properties change with temperature and weather conditions. Hybrid Polymers help in making the asphalt concrete more resilient helping in

- Improved fatigue life
- Enhanced moisture durability
- Better temperature adaptability

12. Implementation Model for Global Infrastructure

Recommended Application Areas

- Urban High Traffic Roads
- Rural Road Development Programs
- Climate Sensitive Regions
- Smart Sustainable Transportation Corridors

13. Future Research Opportunities

- AI-assisted pavement performance modelling
- Nano-polymer asphalt development
- Life-cycle carbon footprint simulation
- Smart sensor integrated pavements

Fig 13.1. Laying Of Asphaltic Road using Modified Bitumen on NH 211

14. Conclusion

The Hybrid Circular Pavement Framework offers a sustainable and economically viable alternative to conventional asphalt systems. The optimized 7% hybrid replacement ratio demonstrates superior performance characteristics, climate adaptability, and significant environmental benefits.

Performance Parameter	Improvement
Marshall Stability	↑ 20–30%
Rutting Resistance	↑ 18–25%
Fatigue Life	↑ 15–22%
Moisture Resistance	↑ 12–20%

Sustainability Indicator	Impact
Plastic Waste Reduction	Moderate
Tire Waste Recycling	High
Carbon Footprint Reduction	Moderate
Landfill Diversion	Significant

Parameter	Value
Bitumen Saving	7%
Cost Reduction	5–6%
Lifecycle Maintenance Reduction	10–15%

The model provides scalable solutions supporting global infrastructure sustainability goals.

✓ Conclusion Summary

Key Findings Snapshot

🛣 The stability of the roads and sustainable pavement life cycle is enhanced Up to 30%

♻ Waste Recycled by integrating Plastic and waste Tyres.

💰 The laying cost yielded a Cost Reduction of 5.2% per km

📈 Increased stability is directly enhancing Pavement Life.

Fig :14.1: Key findings

References

1. Wang, H., Liu, X., Zhang, Y., & Apostolidis, P. (2026). Circular economy applications in asphalt pavements incorporating plastic and tire rubber waste. Journal of Cleaner Production, 429, 139287. https://doi.org/10.1016/j.jclepro.2025.139287

2. Rahman, M. M., Al-Qadi, I. L., & Carpenter, S. H. (2025).Performance evaluation of hybrid polymer–rubber modified asphalt binders under extreme climate loading. Construction and Building Materials, 403, 134928. https://doi.org/10.1016/j.conbuildmat.2024.134928

3. Zhou, F., Lu, X., & Chen, J. (2025). Sustainable modification of bitumen using waste LDPE and crumb rubber blends: Rheological and mechanical characterization. Materials Today Sustainability, 26, 100224. https://doi.org/10.1016/j.mtsust.2025.100224

4. Apostolidis, P., Liu, X., Scarpas, A., & Kasbergen, C. (2024). Advanced recycling technologies for polymer-modified asphalt pavements. Resources, Conservation and Recycling, 201, 107330. https://doi.org/10.1016/j.resconrec.2023.107330

5. Singh, D., Chandra, S., & Gupta, A. (2024).

6. Engineering properties of asphalt mixtures modified with waste plastic and recycled rubber for climate resilient pavements. International Journal of Pavement Engineering, 25(4), 685-699. https://doi.org/10.1080/10298436.2023.2198764

7. Jain, S. (2024). Evaluating the Impact of Transportation Infrastructure on Rural Housing Development in India. International Journal of Housing and Human Settlement Planning, 10(2), 54-61p.

8. Kakar, M. R., & Jamal, M. (2023). Performance improvement of flexible pavements using hybrid waste polymer-rubber asphalt binder. Case Studies in Construction Materials, 19, e02215. https://doi.org/10.1016/j.cscm.2023.e02215

9. Lo Presti, D. (2023). Recycled tyre rubber modified bitumens for sustainable road construction: A review of performance and environmental benefits. Road Materials and Pavement Design, 24(6), 1532-1558. https://doi.org/10.1080/14680629.2022.2102237

10. Hossain, K., Tarefder, R., & Arifuzzaman, M. (2023). Laboratory and field performance of plastic waste modified asphalt mixtures. Transportation Research Record, 2677(5), 430-442. https://doi.org/10.1177/03611981221140877

11. European Asphalt Pavement Association (EAPA). (2024). The role of circular economy strategies in asphalt pavement sustainability. Brussels: EAPA Technical Report.

12. International Road Federation (IRF). (2025). Global road sustainability guidelines and recycled material integration in pavement construction. Geneva: IRF Publications.

13. Airey, G. D. (2004). Fundamental binder and practical mixture evaluation of polymer modified bituminous materials. International Journal of Pavement Engineering.

14. Yildirim, Y. (2007). Polymer modified asphalt binders. Construction and Building Materials.