

Pavement design using waste rubber and plastic

A Arjun¹, Simi K Raveendran², Akhil U S³, Athul Scaria Raju⁴, Aswini S Ani⁵, Maneesh Mathew⁶,
Pranav Pramod⁷, Sreehari Anish⁸

^{1,3,4,5,6,7,8} Member, Toms College of Engineering, Kottayam

² Member, Veltech University, Chennai

Abstract—Urbanization regions, where the accumulation of non-biodegradable materials results in acute ecological hazards. The conventional methods of landfilling and incineration take up valuable sites, land resources, and at the same time emit dangerous types of gases, hence the need for sustainable alternatives.

One of the most ingenious solutions involves adding plastic and rubber wastes to pavement construction that addresses waste management issues, at the same time improving roads performance.

In this study, Low-Density Polyethylene (LDPE), High-Density Polyethylene (HDPE) and Crumb Rubber (CR) were used as asphalt modifiers to improve the mechanical and rheological properties of bituminous binders. Laboratory investigations focused on key performance.

The following parameters are measured: the complex shear modulus G^* , phase angle δ , and rutting factor ($G^*/\sin\delta$), which in total determine the elasticity, stiffness, and rutting resistance of asphalt mixtures under varying temperature conditions.

The results indicate that the addition of LDPE, HDPE, and CR significantly improved binder performance compared to conventional mixes. Among the tested materials, LDPE emerged as the best-performing modifier, in particular. The disposal of plastic and rubber waste has become a critical environmental concern in rapidly

At 10% replacement, where it had the highest enhancement in elasticity and rutting resistance. HDPE presented positive results for 4% content, yielding a balanced improvement in stiffness and resistance to deformation. Crumb rubber showed notable effectiveness at higher temperatures, thereby improving the durability and flexibility of the pavement.

Overall, the use of plastic and rubber waste in pavement design not only reduces environmental pollution but also extends the service life of roads, thus offering cost effective and sustainable infrastructure solution. This approach has shown that it can large-scale implementation, offering dual benefits: waste management and performance improvement in modern highway construction.

Index Terms—Pavement design, Waste management, LDPE, HDPE, Crumb rubber, Asphalt modification, Bitumen performance, Rutting resistance, Elasticity, Sustainable roads, Environmental concern, Plastic waste utilization, Rubber waste utilization.

I. INTRODUCTION

The rapid growth of population, urbanization, and industrialization has considerably increased worldwide consumption of plastics and rubber products. While these materials offer While durability and versatility make traditional plastics a long-lasting material for many applications, their disposal creates a critical challenge due to their non-biodegradable nature. Plastic carry bags, packaging materials, bottles, tires, and other rubber-based products accumulate in the environment, resulting in severe ecological and health hazards. Traditional approaches to hazardous waste disposal are open dumping, landfilling, and Incineration further worsens the situation, as they contribute to soil degradation, groundwater.

Contamination, and emission of toxic gases. Thus, this problem of plastic and rubber waste management is an urgent priority in the achievement of sustainable development goals.

In civil engineering, especially pavement construction, there is a special opportunity to transform this waste into a resource. Flexible pavements, which form the backbone of road networks across developing countries including India, large volumes of bitumen and aggregates. However, conventional bitumen has often suffered from limitations such as:

Susceptibility to rutting, fatigue cracking, and reduced durability under extreme climatic conditions. Scientists and engineers have, therefore, been researching the inclusion of waste plastics and rubber as modifiers in bitumen to improve pavement

performance while simultaneously reducing environmental burdens. Low-Density Polyethylene (LDPE) among other materials are blended in the proposed solution. High-Density Polyethylene (HDPE) and Crumb Rubber (CR) with conventional bitumen. These waste-derived modifiers not only enhance the mechanical and rheological properties of Asphalt, but also contribute to cost savings by reducing reliance on virgin materials. Laboratory tests such as DSR analysis, which covers the measurement of complex modulus

(G^*), phase angle (δ) and rutting factor ($G^*/\sin \delta$), have shown that plastic-and rubber modified binders have enhanced stiffness, elasticity, and resistance to permanent deformation. Among the different materials used, LDPE at 10 percent content showed the most significant it improves elasticity and rutting resistance; therefore, it can be regarded as an effective modifier. HDPE at 4% has also been found to enhance stiffness and stability, while crumb rubber performs especially at higher temperatures, with improved flexibility and long-term durability.

These findings highlight that under specific climatic and geographical conditions, different waste materials can be optimized. Traffic conditions to achieve desirable pavement performance. There are several advantages of incorporating waste plastic and rubber into the road construction process. Environmentally, it reduces the volume of waste entering landfills and lowers the release of harmful pollutants. Economically, it contributes to cost-effective pavement design by extending the service life of roads and reducing maintenance needs. Socially, it promotes sustainable infrastructure development, in line with global goals of resource conservation and Circular economy practices.

This approach represents a win-win solution as it deals with two crucial challenges. the increasing problem of waste management and the need for more durable, high-performance pavements. Adopting this type of greener technologies on a wider scale could Developing countries can significantly enhance their road infrastructure, improve public safety, and contribute to environmental protection. Hence, the utilization of waste rubber and plastic in pavement construction Design thus emerges as the sustainable, innovative, and practical strategy for future road construction projects.

In summary, the use of waste rubber and plastic in pavement design represents a win-win. Solution by addressing two key challenges together: the increasing waste management crisis and the demand for durable, high-performance pavements. Consequently, the use of eco-friendly technologies on a large scale, developing countries can considerably improve road. It improves infrastructure, enhances public safety, and contributes to environmental protection. This Innovative approach not only advances the field of civil engineering but also showcases the essential role of the sustainability practices in the development of future infrastructure systems. Therefore, using Waste rubber and plastic in pavement design are emerging as sustainable, innovative, and practical strategy for modern road construction projects.

II. PROCEDURE

A. Material Selection

In this stage, suitable aggregates, bitumen, waste plastic, and waste rubber are chosen. Their quality is checked to ensure that they meet the required standards for pavement construction.

B. Preparation of Waste Materials

Then, waste plastic is cleaned, shredded, and sieved to the required size, while processing of waste rubber produces crumb rubber or devulcanized rubber. Proper preparation helps both materials blend effectively in the pavement mix.

C. Choosing the Incorporation Method

The plastic and rubber are added to the mix by either a dry process or a wet process. In the dry process, shredded plastic or rubber is mixed with hot aggregates, while in the wet process, plastic or rubber is blended with hot bitumen to produce a modified binder. The choice of method depends on equipment availability and required performance.

D. Mix Design

Standard methods such as the Marshall or Superpave design are used to prepare trial mixes. The mix design studies various percentages of plastic, rubber, and bitumen in order to achieve an optimum-performing mixture for pavement construction.

E. Performance Evaluation

The stability, flow, air voids, viscosity, softening point, rutting resistance, fatigue strength, and moisture susceptibility of the trial mixes are tested. From these

studies, one can determine if the mix improves pavement strength and durability.

F. Field Construction and Quality Control

After determining the optimum mix, it is produced at the mixing plant and used for the field construction of the pavement. Adequate heating, mixing, laying, and compaction practices are followed. Quality control tests are conducted in the field to ensure that the pavement meets minimum desired standards for good performance in service.

III. UNITS

Various steps involved in the design of flexible pavement with the inclusion of waste rubber and plastic include careful selection and preparation of materials, followed by rigorous mix design and performance evaluation. Aggregates are selected to meet standard specifications, while waste plastic is cleaned, shredded, and sieved to sizes typically ranging between 0.6 mm to 2.36 mm and waste rubber is processed into crumb rubber or devulcanized pellets. Modifiers can be added using either the dry process, where shredded material is added to hot aggregates, or the wet process, where they are combined with bitumen in a modified binder. Trial mixes are then prepared, and key parameters such as air voids. When a person ignores these cues, continued financial assistance might reinforce negative behavior and create unhealthy dynamics in the family. (%) voids in mineral aggregate VMA (%), and the % of modifier.

The modifier values have been calculated based on SI units; for instance, the weight of bitumen and modifiers are given in kg and the volume in m³. Performance tests like rutting resistance, stiffness modulus E in megapascals (MPa), fatigue life Smuggling involves the act of secretly carrying or concealing contraband or illegal goods within one's clothing or luggage. Durability tests include resistance to moisture susceptibility, as well as in number of load repetitions. These are done when the optimum mix has been identified. Field construction with proper heating, mixing, laying, and compaction is followed by quality control at the site to produce a sustainable, high-performance pavement that effectively uses waste materials while meeting standard engineering criteria.

IV. HELPFUL HINTS



Fig 1: Pavement design using waste rubber and plastic



Fig 2 : Low density polyethylene



Fig 3: High density polyethylene



Fig 4: Crumb rubber

Table 1: Pavement Properties

Prop.	Conv.	Rubber	Plastic	R+P
Stability (kN)	8–10	10–14	12–16	14–18
Flow (mm)	3–5	2–4	2–4	2–3
OBC (%)	5–6	6–8	6–8	7–9
Soft. Pt (°C)	45–55	55–65	60–70	65–75
Penetration	60–80	40–60	40–55	35–50

Table 2: Advantages / Disadvantages

Mat.	Advantages	Disadvantages
Rubber	More elastic, less cracks	Needs grinding
Plastic	High stability, stiff	Can become brittle
R+P	Best performance	Needs careful mixing

B. References

The purpose of this chapter is to present a survey of past research related to the use of waste rubber and plastic in pavement construction. Current and previous studies are reviewed, with an in-depth look at sustainable pavement materials.

Recycled plastics and rubber for green roads: The case study of devulcanized tire rubber and waste plastics compounds to improve the performance of bitumen by Haider Ibrahim, Stefano Marini, Luca Desidery and Michele Lanotte, published in 2023 [1], presents a study of devulcanized tire rubber combined with LDPE and PP as modifiers of bitumen. The DVR–LDPE composite had the best performance in terms of fatigue resistance and its performance was comparable to high-performance SBS-modified bitumen. According to the authors, this approach valorizes two waste materials simultaneously to foster sustainability. The paper "Utilization of Plastic Waste in Bitumen Mixes for Flexible Pavement" by Dr. S. L. Hake, Dr. R. M. Damgir, and P. R. Awsarmal (2024) studied the incorporation of shredded PET plastic in flexible pavement mixes within a range of 5–15% [2]. The Marshall Stability tests revealed that the addition of 10% plastic enhanced strength, durability, and load-carrying ability with cost savings of approximately 5% or more. The authors claimed that plastic-modified bitumen would help in attaining better pavement

performance and was also friendly to environmental concerns.

Zhen Leng et al. (2021) researched the combined recycling of PET plastic and tyre rubber to formulate new performance-enhancing additives for bitumen [3]. PET was treated with TETA and EA amines to produce functional modifiers. The modified bitumen showed enhanced deformation resistance, durability, and rheological properties. This approach also contributes to waste reduction and circular economy principles.

In the research paper "Eco-Economic Analysis of Utilizing High Volumes of Recycled Plastic and Rubber Waste for Green Pavements," conducted by Gohar Alam, Haider Ibrahim, and Ahmed Faheem in 2024, environmental and economic performance was assessed using LCA and LCCA, respectively [4]. The results indicated a reduction in GHG emissions from DVR + LDPE-modified asphalt by about 54.5%, compared to conventional HMA, and about 14.4% compared to SBS-modified HMA, hence being highly eco-efficient.

In the study, Dr. Shakuntala Misra et al. (2020) researched the application of waste plastic as a modifier in bitumen to enhance the mechanical properties of flexible pavements. Addition of 5-10% plastic resulted in increased softening points, viscosity, stability, water resistance, and deformation control. The study focused on the environmental and economic advantages like lessening the pressure on landfills and reducing dependence on virgin bitumen. Overall, previous studies consistently show that waste rubber and plastic incorporated into bitumen enhance pavement performance, increase durability, improve resistance to rutting and fatigue, and contribute toward environmental sustainability.

C. Abbreviations and Acronyms

LDPE	Low-Density Polyethylene
HDPE	High-Density Polyethylene
CR	Crumb Rubber
DSR	Dynamic Shear Rheometer
G*	Complex Shear Modulus
δ	Phase Angle

G*/sinδ	Rutting Factor
PG	Performance Grade
VMA	Voids in Mineral Aggregate
VFB	Voids Filled with Bitumen
VA	Air Voids
OBC	Optimum Bitumen Content
VG	Viscosity Grade
IRC	Indian Roads Congress
ASTM	American Society for Testing and Materials
IS	Indian Standard
MS	Marshall Stability
MF	Marshall Flow
MM	Modified Mix
HMA	Hot Mix Asphalt
PMB	Polymer Modified Bitumen
RAP	Reclaimed Asphalt Pavement
QC	Quality Control
QA	Quality Assurance
PPE	Personal Protective Equipment (if required in construction process section)
SOP	Standard Operating Procedure

V. CONCLUSION

Utilizing waste plastic and rubber in pavement construction provides an effective and sustainable solution to growing challenges in both areas of waste management and pavement durability. Experimental results using LDPE, HDPE, and crumb rubber show significant improvements in rheological and mechanical properties of bituminous binders. The increased complex modulus- Reduced phase angle δ , and increased rutting factor. Similarly, $G^*/\sin\delta$ confirms that the modified binders have higher stiffness, elasticity, and resistance to permanent deformation compared to conventional mixes. The overall performance of LDPE proved to be the best at 10% replacement among the modifiers studied, which provided excellent resistance to rutting and elasticity. HDPE was found to be useful at low dosage rates for providing balanced stiffness and deformation

resistance at 4% content. Crumb rubber proved better at higher temperatures by enhancing the flexibility and long-term durability. These findings show that further optimization of waste-based modifiers can be done based on climatic conditions, traffic loading, and performance requirements.

From an environmental point of view, embedding waste plastic and rubber into roads greatly minimizes landfill burdens while reducing harmful pollutants typical of traditional waste management. Economically, the method reduces maintenance frequency and prolongs pavement service life, thus is cost-effective compared to traditional materials. In addition, the method contributes to sustainable infrastructure development in line with global circular economy principles.

Consequently, the research work shows that pavement design with waste rubber and plastic can be a feasible, environmentally friendly, and high-performance technique for modern highway construction. Its widespread adoption could have a significant contribution to environmental protection, resource conservation, and improvement in road performance, hence showing great promise as a strategy for infrastructure systems in the future.

VI. APPENDIX

Modifier	Selected %	Reason
LDPE	10%	Highest elasticity and rutting resistance
HDPE	4%	Balanced stiffness and stability
Crumb Rubber	8-12%	Improved flexibility at higher temperatures

Property	Value / Range	Test Method
Bitumen Grade	VG-30	IS: 73
Plastic Type	LDPE, HDPE	—
Rubber Type	Crumb Rubber	—
Plastic Size	0.6 mm – 2.36 mm	Sieve Analysis
Rubber Size	1 mm – 4 mm	Grinding Process
Aggregate Impact Value	< 30%	IS: 2386
Softening Point	48–55°C	R&B Test

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