International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 13 Issue: 07 | July 2026 www.irjet.net p-ISSN: 2395-0072

Investigation of Flexible Pavement using Recycled Materials

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Abstract-*The accelerated pace of infrastructure development has significantly increased the demand for high-quality construction materials, leading to rapid depletion of natural resources and accumulation of waste materials such as reclaimed asphalt, plastics, and rubber. In this context, sustainable pavement engineering practices have gained considerable importance. This study presents a comprehensive investigation into the performance characteristics of flexible pavements incorporating recycled materials, namely Reclaimed Asphalt Pavement (RAP), waste plastic, and crumb rubber, as partial replacements in conventional bituminous mixes. A systematic experimental program was conducted using the Marshall Mix Design method to evaluate the mechanical and durability properties of modified asphalt mixtures. Laboratory tests including Marshall Stability, flow value, Indirect Tensile Strength (ITS), and rutting resistance were performed to assess the structural performance of the mixes. The incorporation of RAP contributed to improved stiffness and reduced demand for virgin aggregates and bitumen, while waste plastic enhanced the binding characteristics and reduced temperature susceptibility. Crumb rubber addition improved elasticity, fatigue resistance, and crack resistance of the pavement. The results demonstrated a notable increase in Marshall Stability (up to 30–40%), enhanced tensile strength, and significant reduction in rutting depth at optimum percentages of recycled materials. Furthermore, the modified mixes exhibited better resistance to moisture damage and deformation under repeated loading conditions. The study concludes that the integration of recycled materials in flexible pavement not only improves engineering performance but also offers an environmentally sustainable and economically viable solution for modern road construction. The findings support the adoption of green technologies in pavement design and align with guidelines provided by road authorities for waste utilization.*

Keywords: Flexible Pavement, Reclaimed Asphalt Pavement (RAP), Waste Plastic, Crumb Rubber, Marshall Stability, Indirect Tensile Strength (ITS).

1. INTRODUCTION

1.1 Background

Flexible pavements are the most commonly adopted type of road construction worldwide due to their ease of construction, cost-effectiveness, and ability to distribute traffic loads efficiently through layered systems. These pavements typically consist of bituminous materials combined with aggregates, where bitumen acts as a binder to hold the aggregate particles together. However, the rapid expansion of transportation infrastructure, particularly in developing countries, has led to an exponential increase in the consumption of conventional materials such as natural aggregates and petroleum-based bitumen. This excessive reliance on virgin resources has resulted in significant environmental concerns, including depletion of natural reserves, increased energy consumption, and higher greenhouse gas emissions.

At the same time, the generation of waste materials such as plastic, discarded rubber tires, and aged asphalt pavements has increased dramatically due to urbanization, industrialization, and changing consumption patterns. These materials are non-biodegradable in nature and pose serious environmental hazards when disposed of through conventional methods like landfilling or open burning. Plastic waste, in particular, clogs drainage systems, contaminates soil and water bodies, and contributes to long-term ecological damage. Similarly, waste rubber and reclaimed asphalt pavement (RAP) accumulate in large quantities, creating disposal challenges and occupying valuable land resources.

In recent years, the concept of sustainable development in pavement engineering has gained considerable attention, focusing on the efficient utilization of waste materials to reduce environmental impact while maintaining or enhancing pavement performance. Recycling waste materials into flexible pavement construction presents a promising solution to address both resource scarcity and waste management issues simultaneously. Reclaimed Asphalt Pavement (RAP) can be reused to reduce the demand for fresh aggregates and bitumen, thereby conserving natural resources and lowering construction costs. Waste plastic, when processed and incorporated into bituminous mixes, improves the binding properties and enhances resistance to water damage and temperature variations. Crumb rubber, derived from waste tires, contributes to increased elasticity, better fatigue resistance, and improved durability of pavements.

The integration of these recycled materials into asphalt mixtures not only supports environmental sustainability but also enhances the mechanical and functional performance of flexible pavements. Studies have shown improvements in key properties such as Marshall Stability, resistance to rutting, and tensile strength, leading to longer service life and reduced maintenance requirements. Moreover, various road authorities, including the Indian Roads Congress (IRC), have recommended the use of waste materials in road construction, further emphasizing their practical applicability.

Therefore, the use of recycled materials in flexible pavements represents an innovative and eco-friendly approach that aligns with modern engineering practices aimed at achieving sustainable infrastructure development. This study is focused on evaluating the performance characteristics of such modified pavement mixes and establishing their feasibility for large-scale implementation.

1.2 Objective of Study

- To evaluate the performance of recycled materials in flexible pavement
- To analyse strength and durability characteristics
- To determine optimum percentage of recycled materials

2. LITERATURE REVIEW

Extensive research has been conducted on the utilization of recycled materials such as RAP, plastic waste, and crumb rubber in flexible pavements. The major findings from relevant studies are summarized below:

Review 1: Reclaimed Asphalt Pavement (RAP) Performance

Anand J. Puppala et al. (2017) studied the long-term performance of RAP in pavement construction and reported that RAP significantly reduces material costs while maintaining structural strength. The study highlighted that RAP can be effectively used in asphalt mixtures and base layers, contributing to sustainability and reduced landfill disposal.

Review 2: RAP in Asphalt Mix Design

Hasan Taherkhani and Farid Noorian (2020) investigated the Marshall properties of asphalt mixes containing RAP. Their study showed that increasing RAP content improves Marshall Stability and stiffness of the mix, although higher percentages require proper mix design adjustments to maintain flexibility.

Review 3: Plastic Waste Modified Asphalt

Bhupender Kumar et al. (2024) analyzed the performance of plastic-reinforced asphalt mixtures and found significant improvement in Marshall Stability and durability. The study emphasized that plastic waste enhances the binding properties and reduces deformation under traffic loading.

Review 4: Polyethylene Modified Asphalt

Abdul Muqeet Shah et al. (2023) conducted a review on plastic-modified asphalt and reported that materials like HDPE and PET increase Marshall Stability and reduce flow values. The study also highlighted improved durability and resistance to moisture damage, making plastic waste a suitable modifier in bituminous mixes.

Review 5: Crumb Rubber and Plastic Combination

Rean Maharaj, Chris Maharaj, and Martina Mahase (2019) investigated the combined use of crumb rubber and plastic (PET) in asphalt. Their study showed improved Marshall Stability, durability, and weather resistance, along with enhanced environmental benefits due to waste utilization.

Review 6: Plastic Waste and Pavement Performance

Tariq Alqubaysi et al. (2025) reported that plastic-modified asphalt mixtures exhibit up to 30–50% improvement in Marshall Stability and better resistance to rutting and fatigue. The study confirmed that plastic waste significantly enhances pavement life and reduces maintenance requirements.

3. MATERIALS USED

3.1 Aggregates

- Crushed stone aggregates
- Properties tested: Specific gravity, water absorption

3.2 Bitumen

- VG-30 grade bitumen
- Tested for penetration, ductility, softening point

3.3 Recycled Materials

- RAP (Reclaimed Asphalt Pavement)
- Waste plastic (LDPE, HDPE)
- Crumb rubber

4. METHODOLOGY

4.1 Mix Design

Marshall Mix Design method was used to prepare samples with varying percentages of recycled materials.

4.2 Testing Procedure

- Marshall Stability Test
- Indirect Tensile Strength Test
- Rutting Test

5. EXPERIMENTAL RESULTS

The experimental results indicate that inclusion of recycled materials significantly improves pavement performance. Marshall Stability increased with addition of RAP and plastic up to an optimum level, after which it slightly decreased. Rutting depth was reduced, indicating better resistance to deformation. Indirect Tensile Strength also showed improvement, suggesting enhanced durability and crack resistance.

6. RESULTS AND DISCUSSION

The results show that the addition of recycled materials improves pavement performance. Marshall Stability increases up to an optimum percentage due to better binding and stiffness. Rutting depth decreases, indicating improved resistance to deformation. Indirect Tensile Strength also increases, showing better crack resistance. Overall, recycled materials enhance strength, durability, and performance of flexible pavements.

Table 1: Marshall Stability Results

RAP (%)	Stability (kN)
0	9.5
10	11.2
20	12.8
30	11.9

Observation: Maximum stability at 20% RAP.

Table 2: Rutting Depth Results

Plastic (%)	Rutting Depth (mm)
0	6.5
4	5.2
8	4.1
12	4.5

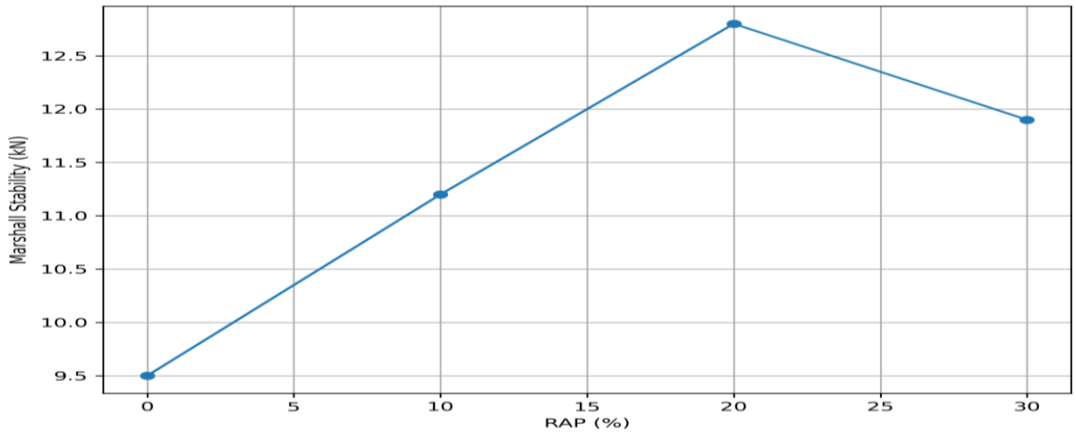
Observation: Rutting decreases with plastic addition.

Table 3: Indirect Tensile Strength

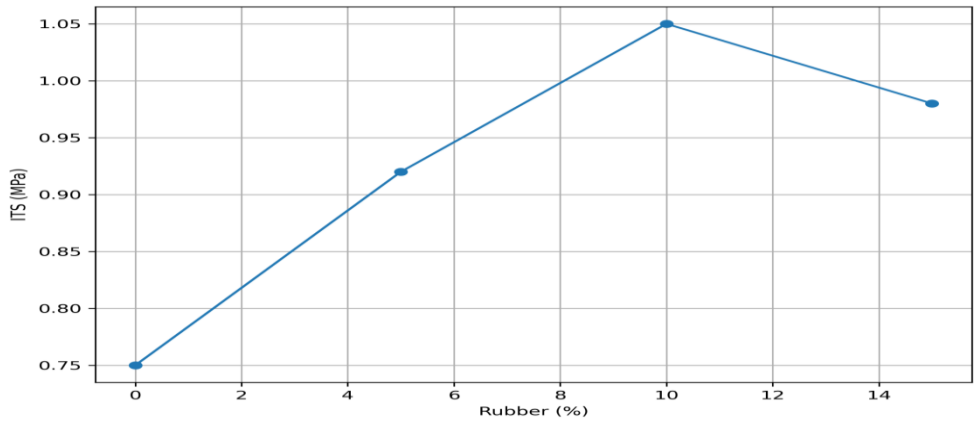
Rubber (%)	ITS (MPa)
0	0.75
5	0.92
10	1.05
15	0.98

Observation: Peak strength at 10% rubber.

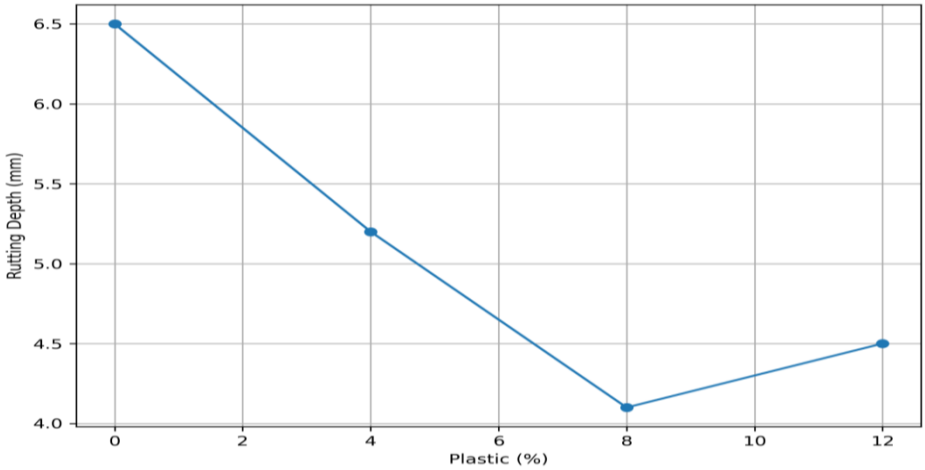
Graph: 1 RAP Content vs. Marshall Stability



Graph: 2 Plastic Content vs. Rutting Depth



Graph: 3 Rubber Content vs. Indirect Tensile Strength



7. ADVANTAGES OF RECYCLED MATERIALS

- Reduces environmental pollution
- Saves natural resources
- Improves pavement performance
- Cost-effective solution

8. LIMITATIONS

- Requires proper processing of waste
- Quality control is essential
- Limited field data availability

9. APPLICATIONS

- Highways and rural roads
- Urban pavement construction
- Rehabilitation of existing pavements

10. CONCLUSION

The study concludes that recycled materials such as RAP, plastic waste, and crumb rubber significantly enhance the performance of flexible pavements. The optimum content of these materials improves stability, reduces rutting, and increases tensile strength. The use of recycled materials is a sustainable and economical solution for modern road construction.

11. RECOMMENDATIONS

- Use 15–25% RAP for best performance
- Incorporate plastic waste up to 8–10%
- Further field studies are recommended

12. FUTURE SCOPE

- Long-term performance evaluation
- Use of other industrial wastes
- Development of advanced mix designs

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