"Utilization of Recycled Plastic Waste in Road Construction"

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Abstract- The utilization of recycled plastic waste in road construction has emerged as an innovative and sustainable solution to address environmental pollution and enhance pavement performance. Rapid urbanization and increasing plastic consumption have resulted in serious disposal challenges due to the non-biodegradable nature of plastics. This study focuses on the use of waste plastic materials such as polyethylene, polypropylene, and polystyrene as modifiers in bituminous mixes to improve the physical and rheological properties of pavements. The shredded plastic is coated over aggregates and mixed with hot bitumen, resulting in enhanced strength, durability, and resistance to deformation. Laboratory tests such as penetration, softening point, viscosity, Dynamic Shear Rheometer (DSR), and Marshall Stability tests were conducted to evaluate performance characteristics. The results indicate significant improvements in stability, stiffness, water resistance, and service life of pavements with optimum plastic content. Additionally, the use of titanium dioxide as a smoke absorbent contributes to reducing vehicular pollution. This approach not only reduces construction costs but also promotes eco-friendly waste management practices and sustainable infrastructure development.

Keywords: Recycled Plastic Waste, Bituminous Pavement, Marshall Stability, Rheological Properties, Sustainable Road Construction etc.

I. INTRODUCTION

Flexible pavements are widely used in India due to their cost-effectiveness, ease of construction, and maintenance advantages. These pavements primarily consist of bitumen as a binding material, which plays a crucial role in determining the strength, durability, and performance of the road under varying traffic and environmental conditions [1]. However, conventional bitumen often fails to meet the increasing demands of heavy traffic loads, temperature variations, and long-term durability, leading to common defects such as rutting, cracking, potholes, and deformation [2].

Bitumen is a viscoelastic material whose behavior depends on temperature and loading conditions. At high temperatures, it behaves like a viscous fluid, while at low temperatures, it exhibits elastic properties. The rheological properties of bitumen, such as complex shear modulus (G^*) and phase angle (δ), are critical in evaluating its resistance to deformation and fatigue [3]. Despite its widespread use, traditional bitumen lacks sufficient resistance to extreme climatic conditions, particularly in regions with high temperature variations, which necessitates the modification of bituminous materials to enhance performance [4].

In recent years, the growing concern over environmental pollution caused by plastic waste has led researchers to explore innovative solutions for waste management. Plastic waste, being non-biodegradable, accumulates in landfills and natural ecosystems, causing severe environmental hazards and contributing to global warming [5]. One promising approach to mitigate this issue is the utilization of recycled plastic waste in road construction as a bitumen modifier.

The incorporation of plastic waste into bituminous mixes improves various engineering properties of pavements. When plastic is shredded and mixed with hot aggregates or bitumen, it enhances binding properties, reduces water absorption, and increases resistance to deformation [6]. Studies have shown that plastic-modified bitumen exhibits higher Marshall Stability, increased softening point, and reduced penetration value, indicating improved strength and durability [7]. Additionally, plastic-coated aggregates help in reducing voids and enhancing the overall performance of the pavement structure [8].

Two primary methods are used for incorporating plastic into bituminous mixes: the wet process and the dry process. In the wet process, plastic is blended with hot bitumen to form a homogeneous mixture, whereas in the dry process, plastic is first coated onto heated aggregates before adding bitumen [9]. Both methods have demonstrated significant improvements in pavement performance, although the dry process is more commonly adopted due to its simplicity and effectiveness.

Furthermore, the addition of recycled plastic contributes to economic benefits by reducing the consumption of conventional materials and lowering maintenance costs. It also provides an effective solution for managing plastic waste, thereby promoting sustainable development and environmental conservation [10]. The use of additives such as titanium dioxide further enhances the environmental benefits by reducing vehicular emissions through smoke absorption [11].

This study aims to evaluate the effectiveness of plastic waste as a modifier in bituminous pavements by analyzing its impact on physical and rheological properties. The research focuses on determining the optimum percentage of plastic content to achieve maximum performance improvements while maintaining cost efficiency and sustainability. The findings of this study contribute to the development of durable, eco-friendly, and cost-effective road construction techniques suitable for modern infrastructure needs.

Waste Collection Source :

The materials which can be used are waste plastic bottles, bags, wrappers, collected from the nearby dumping places of houses and apartments and from the large dump yards. But the collected waste has to be recycled before it can be used with the bitumen. The collected waste should be free from other type of waste such as dust, soil, vegetable etc. and if it not then it should be separated properly. Then it should be cleaned and dried.

Figure 1. Sources of waste plastic

Recycling Process :

i. Selection or analysis: The recyclers have to select and analyze the waste, which are suitable for recycling/reprocessing.

ii. Collection or segregation: The materials which can be used are waste plastic bottles, bags, wrappers, collected from the nearby houses and apartments and from the dump yards.

iii. Transporting or processing: After selection and segregation of the used plastic waste; it shall be washed, shredded, agglomerated, extruded and granulated. Waste plastic was segregated, and shredded using shredding machine (particle size 2-3 mm).

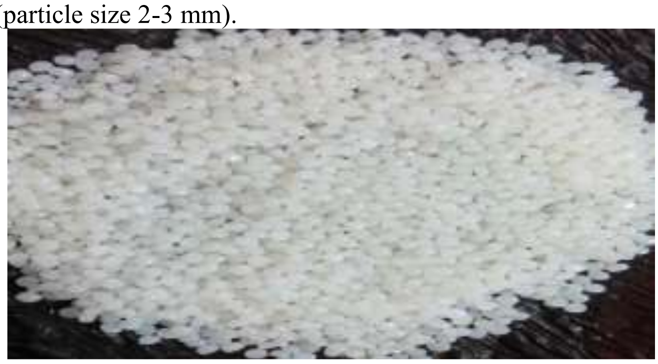

Figure 2. Material after recycling and shredding

II. PROBLEM IDENTIFICATION

- Rapid increase in plastic waste due to urbanization and industrialization has created serious environmental pollution issues, as plastics are non-biodegradable and difficult to dispose of safely.
- Conventional road construction materials such as bitumen are facing performance limitations under heavy traffic loads and extreme climatic conditions, leading to pavement failures like cracks, potholes, and rutting.
- Inefficient waste management systems in developing countries like India result in large quantities of plastic waste being dumped in landfills and open areas, causing soil and water pollution.
- Existing road construction techniques do not effectively utilize waste materials, leading to increased consumption of natural resources and higher construction costs.
- Lack of standardized guidelines and technical awareness for using plastic waste in pavement construction restricts its widespread implementation.
- There is a need to develop sustainable, durable, and cost-effective road construction methods that also address environmental concerns.

III. OBJECTIVE AND SCOPE OF WORK

Objectives :

• Study the quantitative changes in Viscosity, softening point, Penetration value, Marshal Stability and DSR test which is used to describe the viscous and elastic behavior of the modified bitumen at different temperature.
• To find the optimum percentage of plastic waste needed in bitumen for best result of modified bitumen. • To improve Viscosity, Marshall Stability, Penetration value and Softening point of the Bitumen.
• Eco-friendly environment.
• To utilize waste materials as a pavement ingredient (as bitumen modifier).
• To improve the binding property and water resistance of the bitumen.
• Reduction in construction coast of road pavement.

Scope :

With increasing population and industrialization, demand of various development projects, construction of various industrial structures, building and roads have become important. For efficient and optimal design understanding of the behavior of road surface is of prime importance. The scope of present study is:

• The Marshal stability, viscosity, ductility, strength, softening point, penetration value etc. properties of modified bitumen will be improved.
• Vast economical saving.
• Reduced maintenance responsibility.
• Environmentally friendly.
• Improved water resistance of the pavement surface.

Research framework and Significance:

Plastic waste from different sources are increasing in a large amount which is causing hazard to life due to its non-biodegradable nature so we have to reduce it by utilizing it in engineering field by adopting proper techniques. Property of modified bitumen by plastic waste is far better from the pure bitumen in following aspects: -

• The Marshal stability, viscosity, ductility, strength, softening point, penetration value etc. properties of modified bitumen will be improved.
• Vast economical saving.
• Reduced maintenance responsibility.
• Environmentally friendly.
• Improved water resistance of the pavement surface.

IV. LITERATURE REVIEWS

A) Literature Survey

Sharma and Patel (2021) conducted an experimental study on the utilization of waste plastic in flexible pavement construction. The study focused on incorporating shredded polyethylene into bituminous mixes using the dry process. Laboratory tests such as Marshall Stability, penetration, and softening point were performed. The findings indicated that the addition of plastic waste significantly improved the stability and strength of the pavement while reducing deformation under heavy loads. The optimum plastic content was found to be around 6–8% by weight of bitumen. The research concluded that plastic-modified roads are more durable, cost-effective, and environmentally sustainable compared to conventional roads.

Kumar et al. (2021) analyzed the mechanical properties of bituminous mixes modified with recycled plastic waste. The study emphasized the rheological behavior of modified binders using Dynamic Shear Rheometer (DSR) tests. Results showed an increase in complex modulus (G*) and reduction in phase angle (δ), indicating improved stiffness and elasticity. The modified bitumen demonstrated enhanced resistance to rutting and fatigue cracking. The researchers concluded that plastic waste improves the performance of pavements under varying temperature conditions and heavy traffic loads, making it suitable for high-performance road construction applications.

Singh and Verma (2022) investigated the environmental and economic benefits of using waste plastic in road construction. The study highlighted the reduction of plastic waste accumulation in landfills and its effective reuse in infrastructure development. Experimental results showed improved water resistance and reduced moisture susceptibility in plastic-modified pavements. The authors also emphasized cost savings due to reduced bitumen usage. Their findings suggested that this method provides a dual benefit of waste management and improved road performance, making it a sustainable alternative for developing countries like India.

Reddy et al. (2022) evaluated the performance of plastic-coated aggregates in bituminous roads. The study used HDPE and LDPE waste to coat aggregates before mixing with bitumen. Results indicated improved bonding between aggregates and bitumen, leading to higher Marshall Stability and reduced voids. The modified mixes showed better resistance to water infiltration and stripping. The researchers concluded that plastic coating enhances the durability and lifespan of pavements, especially in regions with heavy rainfall and fluctuating temperatures.

Gupta and Mishra (2022) conducted a comparative study between conventional bitumen and plastic-modified bitumen. The study focused on penetration value, softening point, and viscosity. Results showed a decrease in penetration value and an increase in softening point with increasing plastic content, indicating improved hardness and temperature resistance. The modified bitumen exhibited better performance in hot climatic conditions. The authors concluded that plastic waste can effectively enhance the physical properties of bitumen and reduce maintenance costs of roads.

Khan et al. (2023) explored the use of mixed plastic waste in asphalt pavement construction. The study included different types of plastics such as PET, PP, and PS. Laboratory results demonstrated improved tensile strength, reduced rutting, and enhanced load-bearing capacity of pavements. The research also highlighted the role of plastic in improving fatigue life. The authors concluded that mixed plastic waste can be effectively utilized without segregation, making the process more practical and economically viable.

Das and Roy (2023) focused on the durability analysis of plastic-modified roads under extreme climatic conditions. The study involved long-term performance evaluation through simulated temperature and loading conditions. Results indicated that plastic-modified pavements showed superior resistance to thermal cracking and deformation. The authors emphasized that such roads are particularly suitable for hot and humid regions. The study concluded that incorporating plastic waste significantly enhances pavement life and reduces repair frequency.

Mehta and Joshi (2023) studied the impact of plastic waste on the rheological properties of bitumen. Using advanced laboratory tests like DSR and viscosity analysis, they observed that plastic addition increases stiffness and reduces temperature susceptibility. The modified binder showed improved elastic recovery and resistance to permanent deformation. The authors concluded that plastic-modified bitumen provides better performance under dynamic loading conditions and can be used in high-traffic areas.

Choudhary et al. (2024) investigated the large-scale implementation of plastic roads in urban infrastructure. The study analyzed field performance of roads constructed using plastic-modified bitumen. Results showed reduced pothole formation, improved surface quality, and longer service life compared to conventional roads. The authors also highlighted reduced maintenance costs and environmental benefits. The study concluded that plastic roads are a viable solution for sustainable urban development.

Iyer and Nair (2024) examined the sustainability aspects of using plastic waste in road construction. The study focused on lifecycle analysis and environmental impact assessment. Findings revealed a significant reduction in carbon emissions and landfill waste. The modified pavements demonstrated better durability and resource efficiency. The authors concluded that integrating plastic waste into road construction aligns with sustainable development goals and promotes circular economy practices.

B) Research Gap

Despite extensive research on the use of plastic waste in road construction, several gaps still exist. Most studies focus on laboratory-scale analysis, with limited long-term field performance data under real traffic and environmental conditions. Standardized guidelines for optimum plastic content and mix design are still lacking, especially for different climatic regions. The combined effect of various plastic types on rheological properties is not fully explored. Additionally, the environmental impact assessment, including microplastic release and lifecycle analysis, requires further investigation. There is also limited research on large-scale implementation, economic feasibility, and integration of advanced additives like titanium dioxide in practical applications.

V. METHODOLOGY

A) Proposed System

Figure 3. Proposed system.

The working principle of utilizing recycled plastic waste in road construction is based on modifying the properties of conventional bitumen by incorporating processed plastic materials to enhance strength, durability, and performance of pavements. The process begins with the collection of waste plastics such as polyethylene (PE), polypropylene (PP), and polystyrene (PS), which are cleaned, segregated, and shredded into small pieces of about 2–4 mm size.

In the dry process, the shredded plastic is added to hot aggregates heated to around 150–160°C. At this temperature, the plastic melts and forms a thin coating over the surface of aggregates. This coating fills the voids and reduces water absorption, thereby improving the binding properties between aggregate and bitumen. After coating, hot bitumen is added and mixed thoroughly to form a uniform plastic-modified bituminous mix.

In the wet process, plastic is directly mixed with hot bitumen at around 180°C to form a homogeneous blend before mixing with aggregates. This enhances the rheological properties of the binder, such as viscosity and elasticity.

The presence of plastic increases the softening point and reduces penetration, making the pavement more resistant to deformation, rutting, and temperature variations. Additionally, the improved binding and reduced porosity result in better load distribution and longer pavement life. Thus, this technique not only strengthens roads but also provides an eco-friendly solution for plastic waste management.

B) Process used to implement plastic in road construction

The methodology employed in this study encompasses a thorough approach to assessing the potential advantages of integrating waste plastic into bituminous mixes for road pavements. The following steps outline the detailed methodology:

- **Segregation** - Plastic waste sourced from various outlets undergoes meticulous segregation to isolate it from other waste materials. This process ensures the purity of the plastic waste and streamlines its subsequent processing and incorporation into bituminous mixes.

Figure 4. Segregation of plastic

- **Cleaning Process** - The segregated plastic waste undergoes rigorous cleaning and drying procedures to remove any contaminants, debris, or moisture. This step is crucial to guarantee the quality and suitability of the plastic waste for road construction applications. Clean and dry plastic waste enhances the adhesion and dispersion of plastic particles within the bituminous mix, thereby enhancing pavement performance.

Figure 5. Cleaning of plastic

- **Shredding Process** - The cleaned plastic waste is shredded or cut into small, uniform pieces to facilitate its even distribution and integration into the bituminous mix. Proper shredding ensures the homogeneous dispersion of plastic particles throughout the mix, thereby improving the overall stability, durability, and performance of the pavement.

Figure 6. Shredded plastic

- **Collection Process** - Plastic waste particles retained on a 2.36 mm IS sieve are meticulously collected for further processing and incorporation into bituminous mixes. Selecting appropriate particle sizes ensures optimal compatibility and interlocking between plastic particles and other mix components, maximizing pavement performance.

Figure 7. Collection of shredded plastic

Testing of Materials - Various tests are conducted on both aggregate and bitumen to comprehensively characterize their properties. These tests include:

- Aggregate Impact Value Test: Evaluates the resistance of aggregates to sudden impact or shock.
- Los Angeles Abrasion Test: Assess the abrasion resistance of aggregates.
- Water Absorption Test: Measures the water absorption capacity of aggregates, indicating their porousness and susceptibility to moisture damage.
- Specific Gravity Test: Determines the density of aggregates relative to water.
- Stripping Value Test: Assesses the adhesion between aggregate and bitumen, indicating the mix's susceptibility to moisture-induced debonding.
- Penetration Value Test: Measures the hardness or consistency of bitumen.
- Ductility Test: Determines the elongation and flexibility of bitumen.
- Flash & Fire Point Test: Determines the flammability and combustibility of bitumen.
- Softening Point Test: Measures the temperature at which bitumen softens.

Sample Preparation: Marshall Stability samples are prepared using various proportions of plastic waste (e.g., 5%, 10%, and 15%) and without plastic waste. The incorporation of plastic waste into the bituminous mix is systematically adjusted to evaluate its impact on pavement properties, including stability, durability, and resistance to temperature and moisture.

Marshall Stability Testing: Marshall Stability tests are conducted on all prepared samples to evaluate their performance under simulated loading conditions. This test assesses the pavement's resistance to deformation and failure under compressive loads, providing valuable insights into the structural integrity and performance of plastic-modified pavements compared to conventional bituminous mixes.

By adhering to this comprehensive methodology, the study aims to systematically assess the potential benefits of incorporating waste plastic into bituminous mixes for road pavements. Through rigorous testing and analysis, the study seeks to elucidate the effects of plastic modification on pavement properties and performance, contributing valuable insights to the ongoing discourse on sustainable infrastructure development and environmental conservation.

VI. RESULTS ANALYSIS

The experimental investigation was carried out to evaluate the effect of waste plastic on the physical and rheological properties of bitumen. Tests such as penetration, softening point, viscosity, Dynamic Shear Rheometer (DSR), and Marshall Stability were conducted for different plastic contents (0%, 2%, 4%, 6%, 8%, and 10%).

A) Penetration and Softening Point Analysis

Penetration and softening point tests are essential to determine the hardness and temperature susceptibility of bitumen. The addition of plastic significantly affects both properties.

Table 1: Effect of Plastic on Penetration and Softening Point

Plastic Content (%)	Penetration Value (0.1 mm)	Softening Point (°C)
0% (Normal)	65.6	62
2%	47.6	69
4%	36.2	75
6%	30.5	80
8%	24.0	85
10%	21.4	88

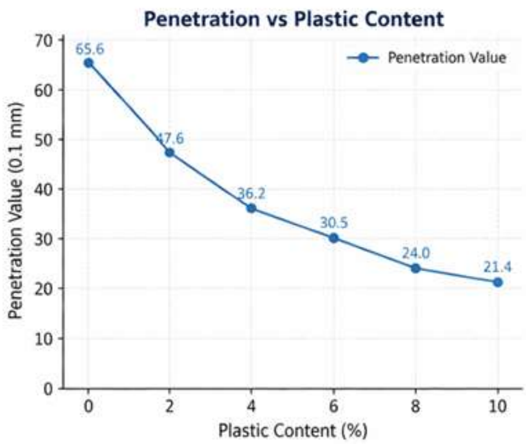

Figure 8. Penetration Vs plastic content

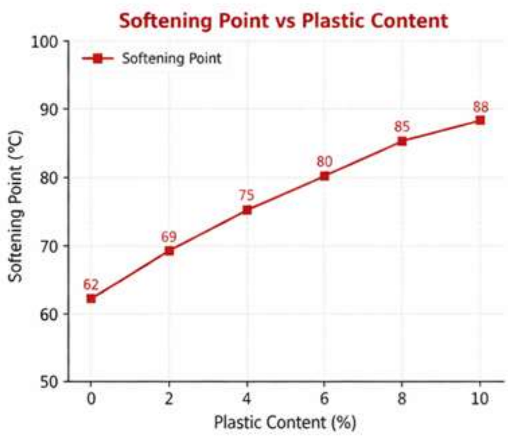

Figure 9. softening point vs plastic content

The penetration value decreases with increasing plastic content, indicating that the bitumen becomes harder and more resistant to deformation. At the same time, the softening point increases, which means the modified bitumen can withstand higher temperatures without softening. This is particularly beneficial in hot climatic conditions like India, where conventional bitumen tends to soften and deform.

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B) Viscosity Analysis

Viscosity determines the flow characteristics of bitumen. Higher viscosity indicates better resistance to deformation.

Table 2: Viscosity Variation with Temperature

Plastic Content (%)	**Viscosity at 135°C (Pa·s)**	**Viscosity at 175°C (Pa·s)**
0%	0.18	0.09
2%	0.22	0.12
4%	0.26	0.15
6%	0.30	0.18
8%	0.35	0.22
10%	0.40	0.25

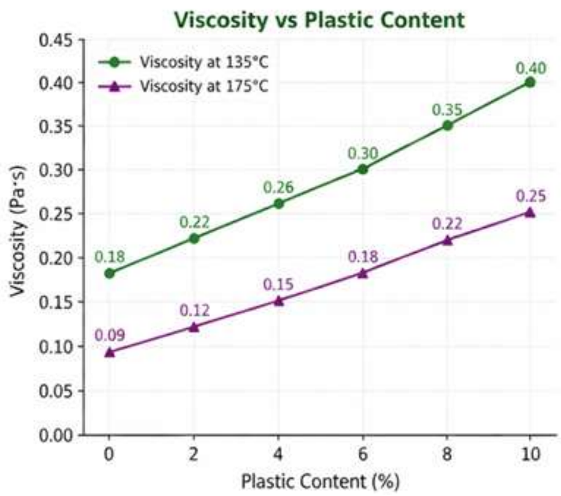

Figure 10. Viscosity vs plastic content

The viscosity increases significantly with the addition of plastic. This indicates improved internal bonding and reduced flow of bitumen under high temperatures. However, excessive plastic content (10%) may reduce workability and flexibility, making it less suitable for practical applications.

C) Rheological Properties (DSR Test)

Dynamic Shear Rheometer (DSR) analysis provides insight into stiffness and viscoelastic behavior.

Table 3: Rheological Properties

Plastic Content (%)	**Complex Modulus G* (kPa)**	**Phase Angle δ (°)**	**G*/sinδ (kPa)**
0%	200	88	205
2%	320	85	350
4%	420	83	450
6%	550	80	600
8%	760	78	878
10%	718	79	800

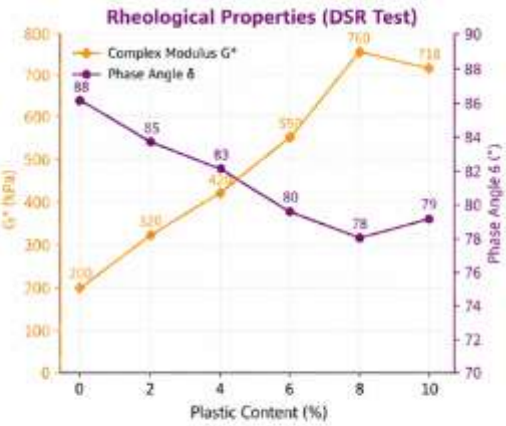

Figure 11. Rheological Properties (DSR Test)

The complex modulus (G*) increases with plastic content, indicating higher stiffness and improved load-bearing capacity. The phase angle decreases, showing improved elastic behavior. The parameter G*/sinδ, which indicates rutting resistance, is maximum at 8% plastic content, suggesting optimum performance.

D) Marshall Stability Analysis

Marshall Stability indicates the load-bearing capacity of pavement.

Table 4: Marshall Stability Results

Plastic Content (%)	**Stability (kg)**	**Flow (mm)**	**Density (g/cc)**
0%	1503	3.8	2.30
2%	2053	3.6	2.32
4%	2113	3.4	2.35
6%	2246	3.2	2.38
8%	2592	3.0	2.40
10%	2224	3.5	2.37

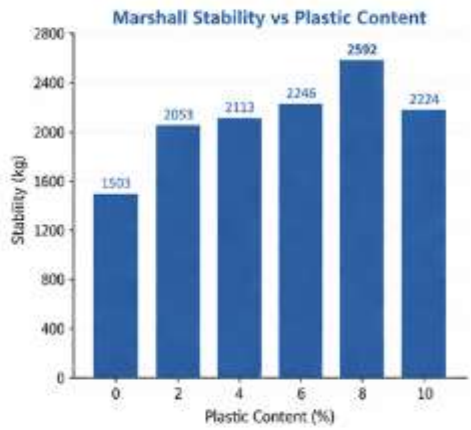

Figure 12. Stability vs plastic content

Marshall Stability increases significantly with plastic addition, reaching a maximum at 8%. This indicates improved strength and resistance to heavy loads. However, at 10%, stability decreases due to reduced flexibility. Flow values decrease initially, indicating increased stiffness, but rise again at higher plastic content.

E) Overall Performance Evaluation

From all test results, the following observations can be made:

- Strength and durability increase with plastic content

- Resistance to temperature and deformation improves
- Optimum plastic content is around 8%
- Beyond optimum level, properties start degrading

The use of plastic waste enhances the mechanical properties of bitumen and provides better performance under heavy traffic and adverse climatic conditions.

The results clearly demonstrate that the incorporation of plastic waste into bitumen significantly enhances the performance characteristics of flexible pavements. The reduction in penetration value and increase in softening point indicate improved hardness and thermal resistance, making the pavement suitable for high-temperature regions. The increase in viscosity reflects better internal bonding and resistance to deformation under load.

Rheological analysis using DSR shows a substantial increase in stiffness and rutting resistance, particularly at 8% plastic content, which is identified as the optimum level. Similarly, Marshall Stability results confirm that plastic-modified bitumen can withstand higher traffic loads with reduced deformation.

However, beyond the optimum percentage, the performance begins to decline due to excessive stiffness and reduced elasticity, which may lead to brittleness. Therefore, proper control of plastic content is essential for achieving desired results.

Overall, the study confirms that plastic waste can be effectively utilized in road construction, providing both engineering and environmental benefits. It offers a sustainable solution to plastic waste management while improving pavement performance and reducing maintenance costs.

VII. CONCLUSION

The present study demonstrates that the utilization of recycled plastic waste in bituminous road construction is an effective and sustainable approach to improve pavement performance while addressing environmental concerns. The experimental results indicate that the addition of plastic significantly enhances key properties such as Marshall Stability, viscosity, and softening point, while reducing penetration value. These improvements lead to increased strength, durability, and resistance to deformation, rutting, and temperature variations.

Among the various plastic contents tested, the optimum percentage was found to be around 8% by weight of bitumen, which provided the best balance between strength and flexibility. Beyond this level, the performance tends to decline due to excessive stiffness and reduced elasticity. The study also confirms that plastic-modified pavements exhibit better water resistance and reduced maintenance requirements compared to conventional roads.

In addition to technical benefits, this method offers an eco-friendly solution for managing plastic waste, reducing landfill burden, and conserving natural resources. Overall, the integration of plastic waste into road construction presents a cost-effective, durable, and sustainable alternative for modern infrastructure development.

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