Performance Evaluation of Polymer (Plastic) Modified Bituminous Concrete Using Dry and Wet Mixing Techniques

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Abstract—**The rapid growth in traffic intensity, axle loads, and environmental variations has exposed the limitations of conventional bituminous pavements, particularly in terms of rutting, cracking, and temperature susceptibility. This study investigates the performance characteristics of polymer-modified bituminous concrete incorporating waste plastic through both dry and wet mixing processes. The primary objective is to enhance the mechanical properties of bituminous mixes while addressing environmental concerns associated with plastic waste disposal. In this investigation, plastic waste in the form of shredded carry bags was utilized as a modifier. In the dry process, plastic was blended with heated aggregates prior to binder addition, whereas in the wet process, plastic was incorporated directly into hot bitumen to form a modified binder. Standard laboratory tests were conducted on aggregates and binders in accordance with Bureau of Indian Standards (BIS) specifications to ensure material suitability. Marshall mix design was employed to determine the optimum binder content (OBC) for both conventional and modified mixes. Comparative analysis revealed that polymer-modified mixes exhibited improved stability, reduced flow values, and enhanced resistance to deformation compared to conventional bituminous concrete. The results indicate that plastic modification, particularly through the dry process, offers a cost-effective and sustainable approach for improving pavement performance.**

Index Terms—**Polymer Modified Bitumen (PMB), Plastic Waste Utilization, Bituminous Concrete, Dry Process, Wet Process, Marshall Stability, Optimum Binder Content (OBC), Flexible Pavement, Rutting Resistance, Sustainable Road Construction, Waste Plastic Recycling, Pavement Performance, Asphalt Modification, Air Voids, Density Analysis.**

I. INTRODUCTION

Bituminous pavements form the backbone of transportation infrastructure, especially in developing countries like India. However, conventional bitumen exhibits inherent deficiencies such as temperature susceptibility, low resistance to permanent deformation, and cracking under repeated traffic loading. With increasing vehicular traffic and axle loads, these limitations result in premature pavement failures. Polymer modification of bitumen has emerged as an effective technique to enhance binder performance. Among various polymers, waste plastic offers dual benefits: improvement in pavement characteristics and mitigation of environmental pollution. The incorporation of plastic waste into bituminous mixes not only enhances stiffness and durability but also contributes to sustainable waste management. Plastic-modified bitumen improves resistance to rutting at high temperatures and reduces brittleness at low temperatures. Two primary techniques are adopted for modification: dry process and wet process. The present study focuses on evaluating and comparing these two methods in terms of engineering performance using Marshall stability analysis.

II. MATERIALS AND METHODS

The materials selected for the present investigation were chosen to represent standard constituents used in bituminous concrete while ensuring compliance with relevant specifications. Coarse aggregates were obtained from locally available crushed stone sources and were selected based on their strength, durability, and angularity, which are essential for achieving adequate interlocking and load distribution in flexible pavements. These aggregates were tested for properties such as aggregate impact value, crushing value, specific gravity, and water absorption in accordance with Bureau of Indian Standards (BIS) procedures, and were found to satisfy the prescribed limits for road construction applications.

Fine aggregates used in the study consisted of natural sand, which plays a critical role in filling voids between coarse aggregates and contributing to the overall stability and workability of the mix. The grading of fine aggregates was carefully controlled to ensure proper packing and to minimize void content. Tests such as sieve analysis and specific gravity were conducted to confirm their suitability as per BIS standards.

The bituminous binder used was conventional paving grade bitumen, commonly employed in flexible pavement construction. The binder was evaluated for its fundamental properties, including penetration, softening point, ductility, and specific gravity. These tests were essential to assess the temperature susceptibility and binding characteristics of the bitumen before modification. The results indicated that the binder met all standard requirements, making it appropriate for both conventional and modified mixes.

Waste plastic, primarily in the form of polyethylene carry bags and similar discarded materials, was used as the modifying agent. The plastic waste was thoroughly cleaned and shredded into small pieces of uniform size to facilitate proper mixing and coating. The selection of plastic as a modifier was driven by its thermoplastic behavior, which allows it to soften and blend effectively with bitumen or adhere to aggregates at elevated temperatures. The incorporation of plastic not only enhances the mechanical performance of the bituminous mix but also provides an environmentally sustainable solution for plastic waste management.

2.2 Mixing Techniques

The incorporation of waste plastic into bituminous mixes was carried out using two established modification techniques, namely the dry process and the wet process. Both methods differ fundamentally in the stage at which plastic is introduced and the mechanism through which modification occurs. A detailed description of each method is presented below.

2.2.1 Dry Process (Aggregate Coating Method)

In the dry process (Fig 2.1), waste plastic is added directly to the heated aggregates prior to the introduction of bitumen. Initially, coarse and fine aggregates were heated to a temperature range of approximately 160–170°C to ensure proper drying and removal of moisture. Shredded plastic waste, typically polyethylene carry bags cut into small uniform pieces, was then added to the hot aggregates in a predetermined proportion (by weight of the total mix).

Upon addition, the plastic softened and melted due to the high temperature of the aggregates, forming a thin coating over the aggregate surfaces. This coating enhances the binding characteristics and reduces the porosity of aggregates. After achieving uniform coating, hot bitumen was introduced into the mixture and thoroughly blended to produce a homogeneous mix.

The dry process is relatively simple, does not require significant modification to conventional hot mix plants, and is widely preferred in field applications. It also improves aggregate–binder adhesion and enhances resistance to stripping and moisture damage.

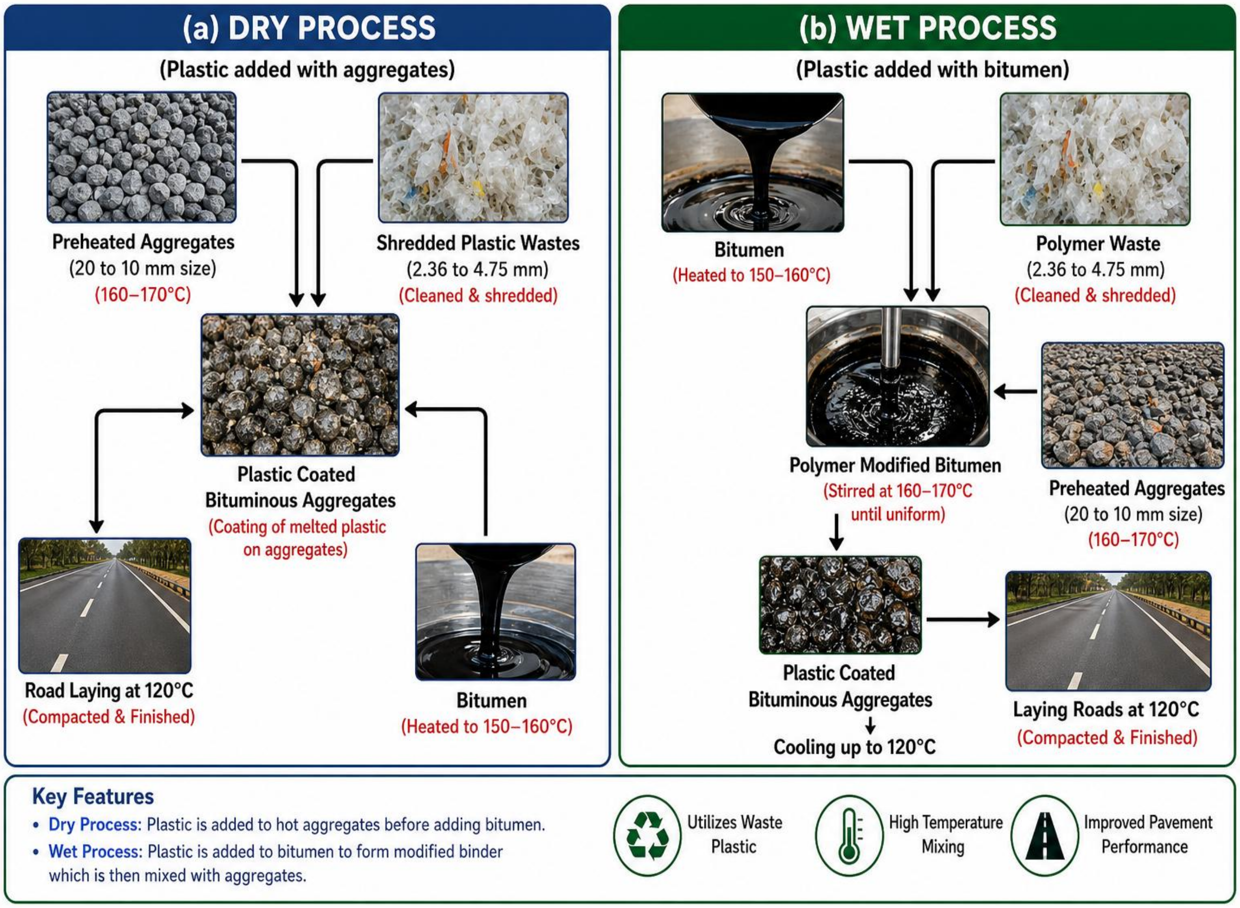

Fig 2.1 a) Wet Process b) Dry Process

2.2.2 Wet Process (Binder Modification Method)

In the wet process, plastic is incorporated directly into the bitumen before mixing with aggregates, resulting in a modified binder. In this method, bitumen was heated to a temperature of about 150–160°C to achieve a fluid state. Shredded plastic was then gradually added to the hot bitumen in a controlled manner (by weight of bitumen), while continuous stirring was maintained to ensure uniform blending.

The plastic melted and interacted with the bitumen matrix, altering its rheological properties such as viscosity, elasticity, and temperature susceptibility. The resulting polymer-modified binder was then used for preparing the bituminous mix by combining it with heated aggregates.

Although the wet process can produce a more uniform and consistent modified binder, it requires additional equipment for blending and strict temperature control to avoid degradation of plastic. This method is generally more suitable for centralized mixing plants with controlled processing conditions.

2.2.3 Key Differences Between Dry and Wet Processes

The dry (Fig 2.2) and wet processes differ in terms of mixing stage, mechanism of modification, and practical implementation. In the dry process, modification occurs at the aggregate level through surface coating, whereas in the wet process, modification occurs at the binder level through polymer-bitumen interaction. The dry process is simpler, cost-effective, and field-friendly, while the wet process offers better control over binder properties but involves higher operational complexity.

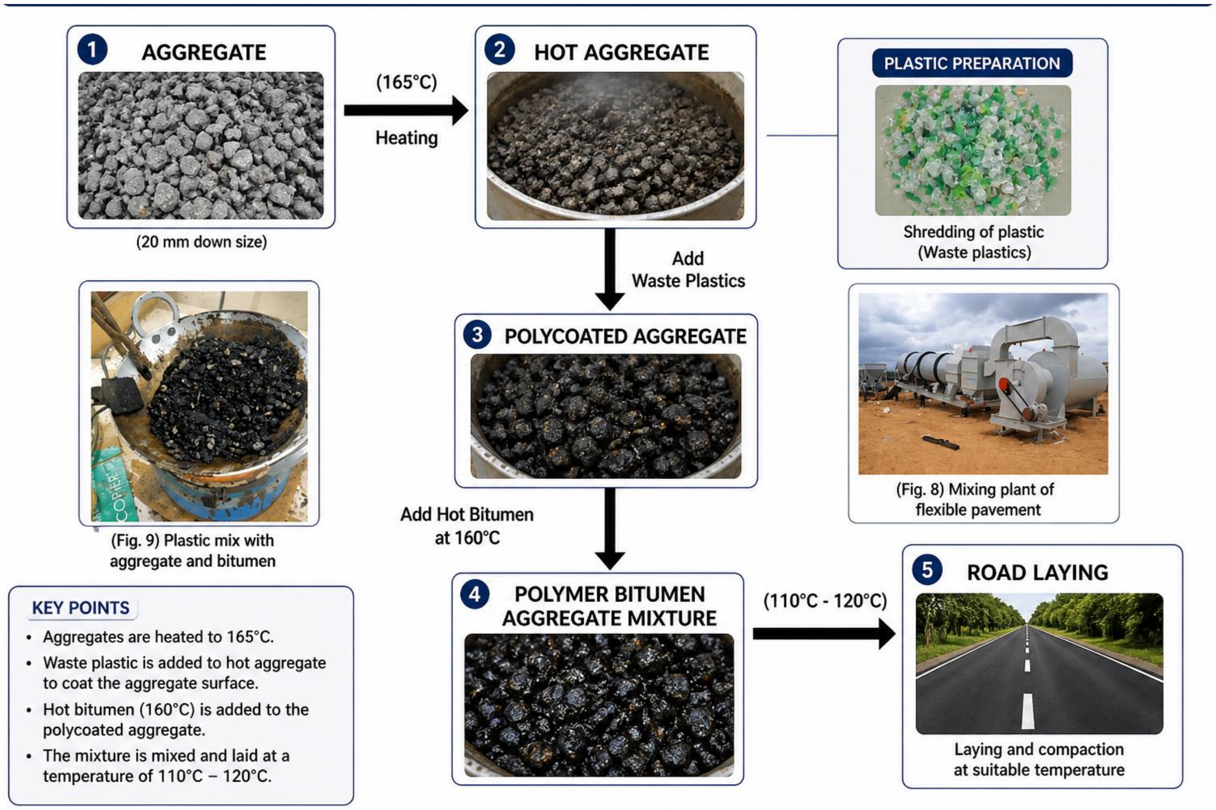

Fig2.2 Construction process of plastic (Dry process)

2.2.4 Significance of Mixing Techniques

The choice of mixing technique significantly influences the performance characteristics of the final bituminous mix (Fig 2.3). The dry process generally enhances stability and resistance to deformation due to improved aggregate interlocking and coating, while the wet process improves binder elasticity and temperature susceptibility. Comparative evaluation of both techniques is therefore essential to determine the most suitable method for practical pavement applications.

Fig 2.3 Marshall process

III. RESULTS AND DISCUSSION

3.1 Material Verification

All constituent materials satisfied BIS requirements prior to mix design. Aggregates exhibited acceptable strength (low impact/crushing values), adequate specific gravity, and low water absorption, ensuring good durability and resistance to disintegration. The base bitumen met penetration, softening point, and ductility limits, confirming its suitability as a control binder. Shredded plastic (predominantly polyethylene) showed stable behavior at mixing temperatures, enabling effective coating (dry process) and blending (wet process).

3.2 Marshall Test Results

Specimens were prepared at varying binder contents (4.5%–6.0% by weight of total mix, in 0.5% increments). For modified mixes, plastic content was kept constant (e.g., 6–8% by weight of bitumen for wet process; 6–8% by weight of total mix for dry process, as per trial optimization).

Table 3.1: Marshall Properties at Different Binder Contents (Conventional Mix)

Binder Content (%)	Stability (kN)	Flow (mm)	Bulk Density (g/cc)	Air Voids (%)
4.5	9.2	3.8	2.28	5.8
5.0	10.5	3.6	2.32	4.9
5.5	11.8	3.5	2.35	4.2
6.0	11.0	3.9	2.33	3.6

Table 3.2: Marshall Properties (Dry Process Modified Mix)

Binder Content (%)	Stability (kN)	Flow (mm)	Bulk Density (g/cc)	Air Voids (%)
4.5	11.5	3.2	2.30	5.2
5.0	13.2	3.0	2.34	4.3
5.5	14.8	2.8	2.37	3.8
6.0	14.0	3.1	2.35	3.2

Table 3.3: Marshall Properties (Wet Process Modified Mix)

Binder Content (%)	Stability (kN)	Flow (mm)	Bulk Density (g/cc)	Air Voids (%)
4.5	10.8	3.4	2.29	5.5
5.0	12.2	3.2	2.33	4.6
5.5	13.5	3.1	2.36	4.0
6.0	12.8	3.3	2.34	3.5

3.3 Determination of Optimum Binder Content (OBC)

The OBC was determined using standard Marshall criteria:

- Binder content corresponding to maximum stability
- Binder content corresponding to maximum bulk density
- Binder content corresponding to 4% air voids

Sample Calculation (Conventional Mix)

- Binder content at maximum stability = 5.5%
- Binder content at maximum density = 5.5%
- Binder content at 4% air voids ≈ 5.6%

$$\text{OBC} = \frac{5.5 + 5.5 + 5.6}{3} = 5.53\% \approx 5.5\%$$

Calculated OBC Values

Mix Type	OBC (%)
Conventional Mix	5.5
Dry Process Mix	5.3
Wet Process Mix	5.4

The slightly lower OBC in modified mixes indicates improved coating efficiency and reduced binder demand due to plastic modification.

3.4 Comparative Performance Analysis

3.4.1 Stability

The dry process mix exhibited the highest stability (≈14.8 kN), followed by the wet process and conventional mix. The improvement (about 20–30%) is attributed to enhanced stiffness and better aggregate interlock due to plastic coating.

3.4.2 Flow Values

Modified mixes showed reduced flow values, particularly in the dry process (≈2.8–3.0 mm), indicating improved resistance to plastic deformation and rutting under load.

3.4.3 Density and Voids

Both modified mixes achieved slightly higher bulk densities and reduced air voids, contributing to improved durability and reduced permeability.

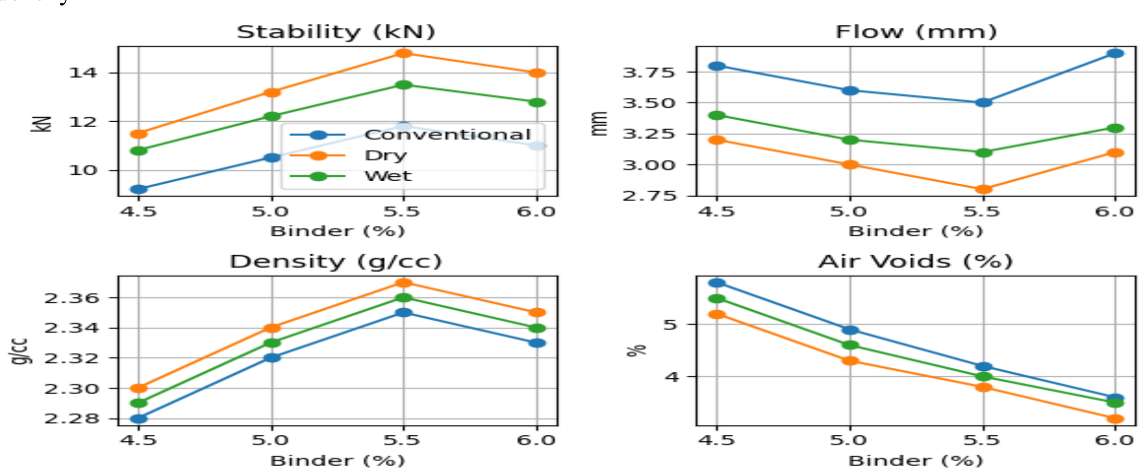

Fig. 3.1: Marshall Mix Design Curves (Stability, Flow, Density, and Air Voids vs Binder Content)

The combined Marshall mix design graph (Fig 3.1) presents the interrelationship between stability, flow, density, and air voids with respect to binder content, enabling accurate identification of the optimum binder content (OBC). The stability curve increases with binder content up to a peak around 5.3–5.5% and then decreases, indicating that excess binder reduces internal friction. The dry process exhibits the highest stability values, demonstrating superior load-bearing capacity compared to wet and conventional mixes.

The flow and density curves further support this behavior. Flow values are lower in modified mixes, particularly in the dry process, indicating improved resistance to deformation. Density increases with binder content and reaches a maximum near the same range as peak stability, reflecting optimal compaction and aggregate interlocking. Beyond this point, density slightly decreases due to the lubricating effect of excess binder.

The air voids curve shows a continuous decrease with increasing binder content, reaching the desirable range of 3–5% near 5.3–5.5%. The convergence of all parameters within this range confirms the OBC. Overall, polymer modification especially through the dry process—enhances strength, durability, and resistance to rutting, making it more effective than conventional mixes.

3.5 Discussion

The results quantitatively confirm that plastic modification significantly improves the engineering performance of bituminous concrete. The Marshall stability of the conventional mix increased from 11.8 kN (peak at 5.5%) to 14.8 kN in the dry process and 13.5 kN in the wet process, indicating an improvement of approximately 25–30% and 15–20%, respectively. This increase is directly attributed to enhanced stiffness and better aggregate–binder interaction. The flow values decreased from 3.5 mm (conventional) to 2.8 mm (dry process) and 3.1 mm (wet process) at the same binder content, reflecting improved resistance to plastic deformation. From the combined graph, the dry process curve consistently lies below the others in the flow plot, confirming higher rigidity and rut resistance.

The bulk density increased from 2.35 g/cc (conventional) to 2.37 g/cc (dry process) and 2.36 g/cc (wet process) at optimum conditions, indicating better compaction and aggregate packing. Simultaneously, air voids reduced from 4.2% (conventional) to 3.8% (dry process) and 4.0% (wet process), improving durability and reducing permeability. Graphically, all four parameters converge within the binder content range of 5.3% to 5.5%, validating the selected OBC values of 5.5% (conventional), 5.3% (dry), and 5.4% (wet). The dry process reaches the desirable 4% air void level earlier, indicating more efficient binder utilization. Overall, the numerical trends and graph convergence clearly establish that the dry process provides the best performance envelope, followed by the wet process, making it the most suitable technique for high-performance and sustainable pavement construction.

IV. CONCLUSION

The study conclusively demonstrates that the incorporation of waste plastic as a polymer modifier significantly enhances the performance of bituminous concrete compared to conventional mixes. Quantitative results show that the Marshall stability increased from 11.8 kN (conventional) to 14.8 kN in the dry process and 13.5 kN in the wet process, while flow values reduced from 3.5 mm to 2.8 mm and 3.1 mm, respectively, indicating improved resistance to deformation and rutting. The bulk density improved up to 2.37 g/cc and air voids reduced to about 3.8%, reflecting better compaction, durability, and reduced permeability. The optimum binder content was identified in the range of 5.3–5.5%, with modified mixes requiring slightly lower binder due to improved coating efficiency. Among the two techniques, the dry process proved superior due to better aggregate coating, higher stability, and ease of implementation without additional equipment. Overall, plastic-modified bituminous concrete offers a technically efficient, economically viable, and environmentally sustainable solution for modern pavement construction, particularly under conditions of increasing traffic loads and temperature variations.

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