# Evaluation of modified bituminous concrete mix developed using plastic waste for a sustainable pavement solution

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**ABSTRACT**

This study investigates the effect of incorporating plastic waste into bituminous mixes for developing sustainable pavement. Low-density polyethylene (LDPE) and high-density polyethylene (HDPE) were used, and the performance and durability of the asphalt mixes were examined by considering various parameters such as air voids, voids in mineral aggregates (VMA), voids filled with bitumen (VFB), and Marshall stability. The essential qualities & performances of asphalt mixes to ensure the preliminary investigation of bitumen and aggregates, such as specific resistance, sieve analysis, abrasion & impact resistance, flakiness index, softening point, penetration, etc., were also carried out. When the bitumen percentage is increased from 5% to 7%, the decrease in air void varies from 8.13% to 3.63%, and VMA is slightly increased from 23.04% to 24.52%. The VFB increases from 64.81% to show the strong bitumen bonding in the asphalt mix. The Marshall stability test confirms the asphalt mix's enhanced resistance. The void characteristics depend on the influence of plastic waste, such as VMA and VFB. The VMA showed more fluctuation for the HDPE mix, varying from 21.85% to 22.62%, and VMA slightly decreased from 22.45% to 22.4% for the LDPE mix. Similar variation in VFB was observed with increasing plastic waste, implying a possible impact of plastic type on void characteristics of asphalt mixes. In conclusion, the findings of this study provide valuable insight into the relationship between LDPE and HDPE and various properties such as bitumen content, plastic waste percentage, and volumetric and mechanical properties of asphalt mixes.

KEYWORDS: *Plastic waste, Low- and high-density polyethylene, Asphalt mix, Bituminous mix, Pavement, Mechanical properties, LDPE and HDPE.*

## 1. Introduction:

Building roads, the usual way harms the environment because we use materials that aren't sustainable. Also, there is a lot of plastic waste causing a big problem. This research is looking into whether we can mix plastic waste into the materials used for roads to make them more environmentally friendly. In today's world, removal of plastic waste is a challenge for everyone. For providing a sustainable solution, a wide area of research has been carried out on incorporating plastic waste into construction materials. The uses and its applications include energy-efficient insulation, weather-resistant bricks, paver blocks, and sidewalks, among others.

In the recent years, this plastic waste is also utilized in the pavement enhancing asphalt, which results in good durability and reduced road wear. However, the challenge persists in collection of plastic waste, sorting and segregating them, as well as ensuring standardization to achieve consistent quality. These researches gives general guidance on how plastic waste can be utilized and handled for construction purpose [1-6].

Particular emphasis has been made on utilizing plastic waste in laying roads. These studies include making plastic-coated aggregate (PCA), plastic waste, and bitumen to enhance flexible pavement engineering properties. In some studies crumb rubber is included for bitumen modification. Recycling waste rubber and plastic into hot mix asphalt is one of the best solution for a sustainable infrastructure. In few cases, waste tires are powdered and blended with bitumen for the enhancement of road strength. This innovative method efficiently utilizes road construction waste materials while road construction waste materials while facilitating organic waste conversion into manure. PET-derived additives, treated with amines, enhance rubberized bitumen performance [7-12].

Literature recommends an addition of 4% of plastic waste as a modification in bitumen for flexible pavement. The plastic waste is heated to a temperature range of 160 °C–170 °C and is mixed with the bitumen. Recycled polyethylene improves viscosity, cohesive strength, and heat resistance of bitumen, reducing the need for expensive polymer modifiers. Researchers recommend using plastic waste in subgrade road construction as an effective alternative for strengthening expansive soils. [13-15].

The conventional bituminous mix depends on the use of nonrenewable resources which is a major threat to the environmental sustainability of road construction projects in the current world. Also, the problem of plastic waste has become acute throughout the whole world, which calls for new approaches to its proper disposal. The present research focuses on this major challenge and offer a solution by examining the potential of employing plastic wastes in the production of bituminous mixes for asphalt road construction. The main aim of this study is to revolutionize the infrastructure of roads and to assist in environmentally safe approaches and also to prevent the negative impact of plastic waste on the environment.

A number of studies conclude that application of waste plastic in bituminous mixes improves their engineering properties. Indian Road Congress (IRC: SP: 98-2013) "Guidelines for the use of waste plastic in hot bituminous mixes (dry process) in wearing courses" provide guidelines for utilization of plastic waste in flexible pavements highlighting following advantages and limitations.

## 2. Materials and methods:

Plastic waste was collected from Aiyamputhur, Tiruchirapalli, India. They have a shredder machine which was used to cut the plastic waste into small pieces.

### 2.1 Tests on Coarse Aggregate:

The following tests on coarse aggregates were carried out as per the mentioned Indian Standard.

1. Specific Gravity Test [IS: 2386 part III 1963][26]
2. Water Absorption Test [IS: 2386 part III 1963]
3. Los Angels Abrasion Test [IS: 2386 part IV]
4. Aggregate Impact Value Test [IS: 2386 part IV 1963]
5. Sieve Analysis [IS : 2386 part I 1963]
6. Flakiness Index [IS: 2386 part I 1963]
7. Elongation Index [IS: 2386 Part I 1963]

The specific gravity of the given aggregate was found to be 2.5 which typically falls in range of 2.5 to 3.0 for aggregates used in road construction (as per IS 2386 Part III) with a water absorbing capacity of 1%. The percentage of wear is observed as 1.4% and the aggregate impact value is found to be 16.11%. the flakiness index and elongation index are found to be 8.57% and 8.37% respectively. The tested aggregate properties are well within acceptable limits for use in road construction. The low wear percentage, acceptable impact value, and favourable shape indices (flakiness and elongation) indicate high-quality aggregates suitable for bituminous and non-bituminous pavements. This aggregate is ideal for applications with moderate to heavy traffic loads.

### 2.2 Tests on Bitumen:

The following tests were carried out on Bitumen. Figure 1 shows the tests carried out.

8. Specific Gravity of Bitumen [IS 1202: 2021]
9. Bitumen Extractor [IS 1211: 2022]
10. Ductility test [IS:105-1978]
11. Softening Point [IS:1205-1978 or ASTM D36]
12. Viscosity test [IS1206 Part 2: 2022]
13. Penetration Test [IS1203-1978]

**Ductility Test** **Viscosity Test** **Softening Point**

**Fig. 1** Tests on Bitumen

Testing the bitumen properties, the specific gravity was found to be 0.9. From the result, it was found that the tested sample carried 5.2% bitumen, having an acceptable range of 4.5% to 6.5% by MoRTH (Ministry of Road Transport and Highways). The ductility test at 30°C shows a result of 76.4 mm, confirming the bitumen's flexibility and suitability for its 30/40 grade. The softening point of the material is found to be 57°C.The penetration value of the bitumen is 32 mm. The viscosity of the binder at 84°C is 920 seconds for 50 ml flow.

## 3. Experimental Investigation:

Preliminary test on aggregates such as Specific Gravity Test, Water Absorption, Los Angels Abrasion Test, Impact Test, Sieve Analysis, Flakiness Index and Elongation Index were conducted. Test on Bitumen viz., Specific Gravity of Bitumen, Bitumen Extractor, Ductility, Softening Point, Penetration and Viscosity were performed to assess the various properties of Bitumen used in the asphalt mix.

The basic properties essential for designing the bituminous mix were arrived from the results of various tests which include Marshall Stability and bitumen test and volumetric properties like bulk density (Gm), theoretical density (Gt), volume of air voids (Va), volume of bitumen (Vb), voids in mineral aggregates (VMA), voids filled with bitumen (VFB).

## 4. Results and Discussion:

The results of various tests include Marshall Stability and bitumen test and volumetric properties like bulk density (Gm), theoretical density (Gt), volume of air voids (Va), volume of bitumen (Vb), voids in mineral aggregates (VMA), voids filled with bitumen (VFB) required for bituminous mixes are analysed.

The equations to calculate air voids (AV), voids in mineral aggregates (VMA), and voids filled with bitumen (VFB) are:

**Percent air voids (Vv)**

$Vv = (Gt - Gm)/Gt \times 100$, where $Gt$ is the theoretical specific gravity of the mixture and $Gm$ is the bulk density or mass density of the specimen

**Percent voids in mineral aggregate (VMA),** $VMA = Vv + Vb$, where

$Vv$ is the volume of air voids and $Vb$ is the volume of bitumen

**Percent voids filled with bitumen (VFB),** $VFB = Vb \times 100/VMA$, where $Vb$ is the percent bitumen content in the mix and $VMA$ is the percent voids in the mineral aggregate

VMA is the volume of voids in the aggregates, and is the sum of air voids and the volume of bitumen. It indicates the available space for bitumen to coat each aggregate particle.

### 4.1 Volumetric properties of bituminous concrete mixes

Figure 2 demonstrates the relationships between three parameters and bitumen content viz., Air Voids (AV), Voids in Mineral Aggregate (VMA), and Voids Filled with Bitumen (VFB). Increase in the bitumen content, exhibit a decreasing trend in air voids, showing that higher bitumen content dccreases the space of voids within the mix, increasing its compaction. VFB and VMA contrarily display an ascending pattern with rising bitumen content. VMA which calculates the total void space in aggregates shows higher volume of bitumen due to displacing aggregate particles. Likewise, the increasing trend in VFB shows a larger proportion of voids of aggregates is being filled with bitumen and also mix cohesion is improved. The optimal balance recommends a trend between these parameters and is crucial for stability mix and performance, as insufficient or excessive bitumen content can adjust permeability, durability or strength.

For different bitumen concentrations, the volumetric characteristics of bituminous concrete mixtures were evaluated. The steady decrease in air voids (AV) is shown with a greater bitumen of a denser composition ranging from 8.131% to 3.638% when the percentage of bitumen increased from 5% to 7%. It reveals a minor increase of the Voids in Mineral Aggregates (VMA) from 23.046% to 24.552%, recommending an increase of space of bitumen is available in the asphalt mix. It shows a gradual rise of the percentage of Voids Filled with Bitumen (VFB) increasing from 64.8% to 85.3% showing enhanced bonding of bitumen and filling capacity of bitumen. For both measured and corrected values, Marshall stability is displayed on an overall uptrend, implying that enhanced resistance to deformation and structural integrity is improved with increased bitumen content. The crucial role of bitumen content in shaping the volumetric and mechanical properties of bituminous concrete mix is needed for optimizing the durability and pavement performance.

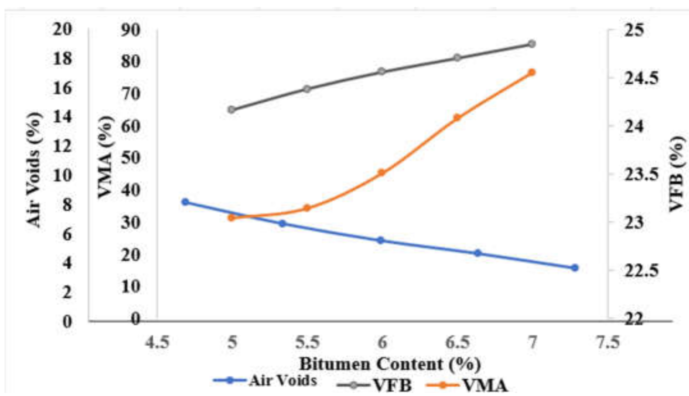


**Fig.2** Volumetric Properties of Bituminous Concrete Mixes

### 4.2 Marshal Stability analysis

Through a series of test results the relationship between Marshall Stability and bitumen content was examined. When the bitumen content ranging increase from 5% to 6%, Marshall stability increases from 9.4 kN to 11.96 kN. However, a sudden increase to 6.5% stability results in a minor decrease to 10.7kN. This recommends a non-linear relationship between bitumen content (in percentage) and Marshall stability (in kN). The bitumen content rising with increase in stability is initial, reaching a peak at 6.0% with a value of maximum nearly 12kN. Beyond this point the further increases bitumen content result in a stability declination. An optimal bitumen content recommends that the trend exist around 6.0%; the maximum strength of the mixture is achieved. To reduce the stability, the bitumen levels below or above are optimum due to insufficient bonding (at lower contents) or excessive lubrication (at higher contents). The crucial observation for pavement design is to ensure durability and structural performance.

The bar chart (in figure 3) indicates Marshal Stability for two types of plastics, LDPE (low-density polyethylene) and HDPE (high-density polyethylene). When the plastic content increases from 4% to 8%, both LDPE and HDPE improve Marshall stability; HDPE compatibly achieving stability is higher than LDPE. Hence the optimum Plastic content is 8%. For HDPE, stability peaks approximately at 15 kN, and LDPE is slightly less. However, when the plastic content is 10%, a decrease in stability for LDPE is observed while high value is maintained at HDPE.

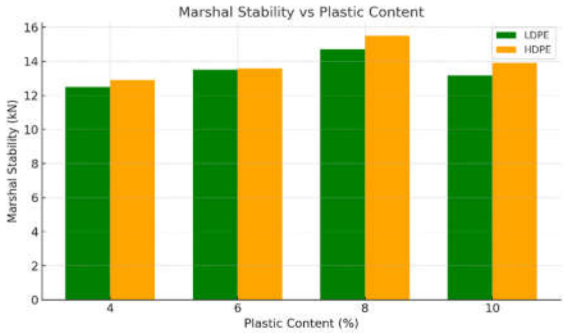


**Fig.3** Marshal Stability vs plastic content

To enhance stability, HDPE performs better than LDPE when plastic content is particularly high. About 8% of the ideal plastic appears in both materials, with the exception of LDPE efficacy diminishes.

### 4.3 Volumetric and Mechanical properties of LDPE and HDPE

The volumetric and mechanical properties of LDPE and HDPE in the various percentages across the plastic waste data are outlined in figure 4. The 4% of LDPE and HDPE waste demonstrates air voids of 4.22 and 4.07, respectively and Marshall Stability ranges from 12.51 to 13.77 kN. It is observed that when the waste content increases to 10%, air voids decrease, with the Marshall stability varying between 13.16 and 16.92 kN. The results illuminate the significant influence of waste percentage on both mechanical stability and voids analysis. These relationships understand that vital role for making informed decisions regarding the recycled plastics utilized, particularly ensuring efficient and sustainable material usage in engineering and construction applications.

The void percentage for different types of plastic waste (LDPE and HDPE) is demonstrated in the bar chart, across various percentages (4%,6%,8%, and 10%). The following Void parameters are considered includes such as Air Voids (AV), Voids Filled with Bitumen (VFB), and Voids in Mineral Aggregate (VMA). The plastic waste across all percentages, LDPE and HDPE reveals higher VFB values, showing 80% of efficient void filling is gradually near the VFB Values. For both the plastic types ranging from 15% and 25% of VMA values remain moderate at the same time AV values are relatively low (under 5%). The data recommends that including plastic waste percentages higher does not importantly alter the sequence performance of voids, with frequently dominating, followed by AV and VMA for both LDPE and HDPE.

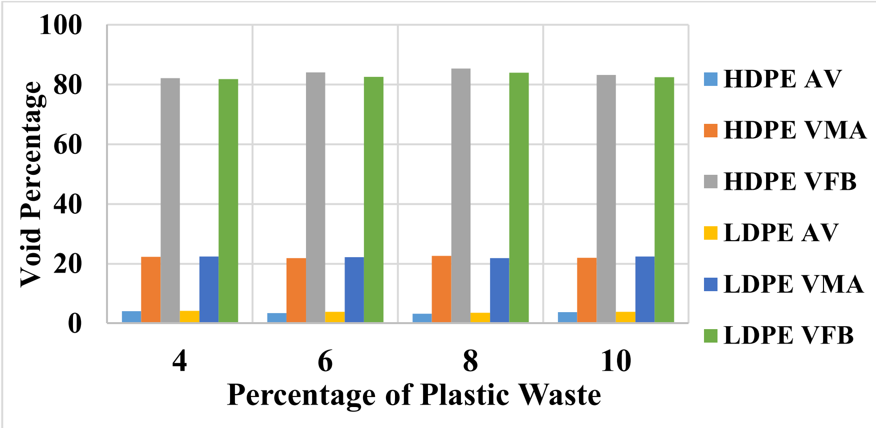


**Fig.4** Percentage of plastic waste vs different void percentages (AV, VMA, VFB)

### 4.4 Air Voids in bituminous mix replaced by plastic waste

Figure 5 implies the impact of plastic waste percentage of air voids for LDPE and HDPE. Since the waste content increases from 4% to 10%, similarly air voids decreases in both materials. In air void percentage LDPE exhibits high compared to HPDE through all waste levels. The structure of LDPE have a higher tendency to trap air compared with HDPE and it also influence overall performance in certain applications.

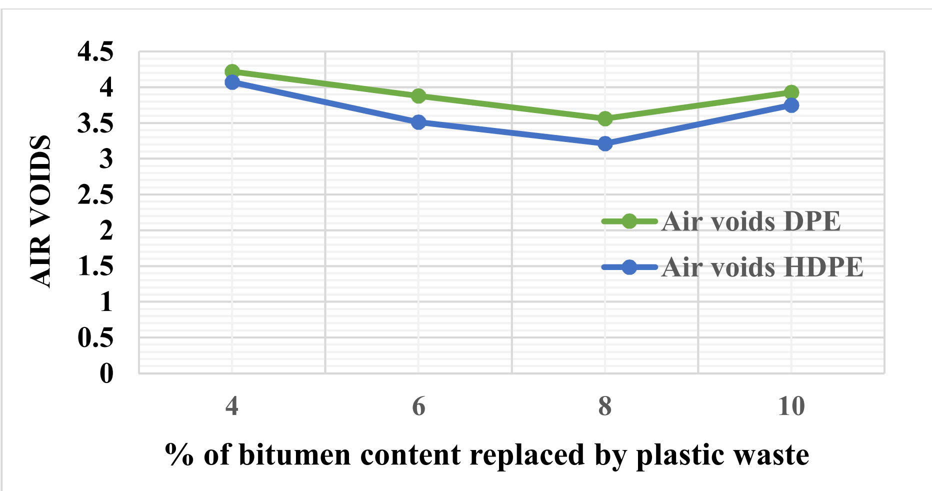


**Fig.5** Air voids vs Percentage of plastic

### 4.5 Plastic waste in voids filled with bitumen (VFB)

The changes in voids filled with bitumen (VFB) vary with the percentage of plastic waste for LPDE and HDPE is represented in figure 6. As the waste content increases from 4% to 10%, both LDPE and HDPE show fluctuations in VFB. LDPE ranges from 81.885% to 82.48%, while HDPE varies from 82.15% to 85.36%. This variability indicates the potential influence of plastic type on the voids filled with bitumen in asphalt mixtures.

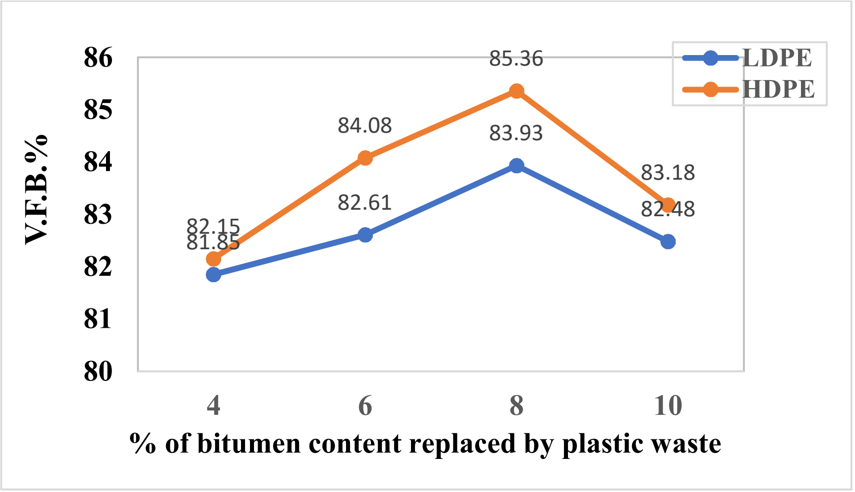


**Fig. 6** Bitumen Content vs VFB %

## Conclusion:

The volumetric properties of bituminous concrete mixes conducted on the comprehensive analysis and the influence of plastic waste on these properties are coupled with the investigation for optimizing pavement performance and durability has yielded valuable essentials needed.

- The relationship between various volumetric properties and bitumen content was examined; the bitumen content raised from 5% to 7% was observed, and remarkable alterations occurred. Air voids (AV) drop steadily from 8.13% to 3.63%, showing a higher bitumen content with denser composition. On the contrary, Voids in Mineral Aggregates (VMA) showed a slight ascent from 23.6% to 24.5%, recommending a marginal raise in the bitumen space available within the mix. The percentage of voids filled with bitumen (VFB) showed a compatible rise, increasing from 64.85% to 85.2%, showing improved filling capacity and bitumen bonding. It showed an overall uptrend of Marshall Stability, recommending enhanced resistance to deformation, and bitumen content is increased with the improvement of structural integrity.
- Furthermore, the investigation into the impact of plastic waste on asphalt mix properties revealed intriguing findings. LDPE (low-density polyethylene) and HDPE (High-density polyethylene) with varying waste percentages demonstrated fluctuations in air voids and Marshal stability. LDPE stability increased from 12.51 to 14.7 kN as waste percentage rose from 4% to 8%, while HDPE stability varied more, peaking at 15.51 kN with 8% waste. When increasing waste content, both the materials exhibited fluctuations in stability; the complex relationship between plastic waste percentage and asphalt mix properties was highlighted.
- The Void characteristics on the influence of plastic waste such as VMA and VFB varied between LDPE and HDPE. VMA LPDE's slightly dropped from 22.45% to 22.4%, and VMA HDPE's displayed more fluctuation, ranging from 21.85% to 22.62%. Similarly, fluctuations in VFB were examined with raising plastic content for LDPE and HDPE, recommending the plastic type of potential influence on void characteristics within the asphalt mixes.

- The crucial data provided for tests on aggregates and bitumen in addition to water absorption, abrasion resistance, specific gravity, impact resistance, ductility, flakiness index, elongation index, softening point, ductility, viscosity, and penetration. The physical and mechanical properties of aggregates and bitumen of these tests offerghts into the need for ensuring the performance of asphalt mixes and quality.
- In Conclusion, The highlight of this study is the complicated relationship between plastic waste concentration, bitumen content, and different volumetric and mechanical characteristics of asphalt mixes. The crucial role for knowing these linkages is improve pavement design, increasing durability, and enhancing eco-friendly maintenance and road construction. Extensive area of research can delve deeper into particular mechanisms underlying the impact of plastic waste on asphalt mix and bitumen content properties, eventually contributing more resilient to the development and pavement eco-friendly materials.

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