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Performance Evaluation of Bituminous Mixes Modified with Waste Plastic and Crumb Rubber for Sustainable Pavement Construction

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Abstract: The present study investigates the performance evaluation of bituminous mixes modified with waste PET plastic and crumb rubber for sustainable pavement construction. In this study, conventional Bituminous Concrete (BC) mix and modified BC mixes were prepared using 60/70 penetration grade bitumen, coarse aggregates, fine aggregates, quarry dust as mineral filler, waste PET plastic, and crumb rubber obtained from discarded automobile tyres. Marshall Mix Design methodology was adopted to evaluate the engineering properties of the mixes. The Optimum Binder Content (OBC) for the conventional mix was determined by conducting Marshall Stability tests at different bitumen contents of 5%, 5.5%, 6%, 6.5%, and 7%. The Marshall Stability, Flow Value, Bulk Density, Air Voids (Vv), Voids in Mineral Aggregate (VMA), and Voids Filled with Bitumen (VFB) were evaluated. The Optimum Binder Content of the conventional mix was found to be 5.1%. Modified bituminous mixes were then prepared by incorporating PET plastic and crumb rubber at proportions of 3%, 4.5%, 6%, 7.5%, and 9% by weight of bitumen. The results revealed that the Marshall Stability increased with the addition of modifiers up to an optimum level and decreased thereafter. The maximum Marshall Stability value of 23.00 kN was obtained for the PET modified mix at 6% PET content, while the crumb rubber modified mix exhibited a maximum stability of 22.64 kN at 6% crumb rubber content. Both modified mixes showed improved performance compared to the conventional mix, which exhibited a stability value of 21.84 kN.

Keywords: Waste Plastic, Crumb Rubber, Bituminous Mix, Flexible Pavement, Sustainable Construction.

I. INTRODUCTION

Transportation infrastructure plays a vital role in the economic growth and social development of a country. Roads are the most widely used mode of transportation in India because they provide connectivity between villages, towns, cities, industrial areas, educational institutions, hospitals, and commercial centers. A good road network facilitates the movement of people and goods efficiently and contributes significantly to national development. India has one of the largest road networks in the world. Due to rapid urbanization, industrialization, and population growth, the volume of traffic on roads has increased considerably over the last few decades. Heavy traffic loading, increasing axle loads, and changing climatic conditions have created challenges in maintaining pavement performance and serviceability. Flexible pavements are commonly used for highway construction in India because of their ease of construction, lower initial cost, and maintenance flexibility.

Bitumen acts as the binding material in flexible pavements. However, conventional bitumen pavements often experience problems such as rutting, cracking, stripping, pothole formation, fatigue failure, and moisture damage. Therefore, there is a growing need to improve the engineering properties of bituminous mixes to enhance pavement performance and durability. At the same time, disposal of waste plastic and waste tyres has become a major environmental concern. Millions of tonnes of plastic waste and rubber waste are generated annually, creating serious environmental and health problems. Utilization of these waste materials in road construction offers an effective solution for waste management while improving pavement performance. The present study focuses on the performance evaluation of bituminous mixes modified with waste plastic and crumb rubber for sustainable pavement construction.

II. METHODOLOGY

The quality and performance of bituminous pavements largely depend upon the properties of materials used and the methodology adopted during mix design and testing. Therefore, careful selection of materials and proper laboratory evaluation are essential for achieving durable and sustainable pavement construction. In the present investigation, waste plastic (PET bottles) and crumb rubber obtained from waste automobile tyres were utilized as modifiers in bituminous concrete mixes.

MATERIALS USED IN THE STUDY:

All materials used in the present investigation were carefully selected and tested in accordance with relevant Indian Standards (IS) and Ministry of Road Transport and Highways (MoRTH) specifications before their utilization in the preparation of bituminous mixes. In the present study, conventional Bituminous Concrete (BC) mixes and modified bituminous mixes were prepared using 60/70 penetration grade bitumen, coarse aggregates, fine aggregates, quarry dust as mineral filler, waste Polyethylene Terephthalate (PET) plastic, and crumb rubber obtained from discarded automobile tyres. Bitumen was used as the binding material, while aggregates provided the structural framework of the mix. Quarry dust was incorporated as a filler material to improve the density and stability of the mix. Waste PET plastic and crumb rubber were used as modifiers to enhance the engineering properties of the bituminous concrete and to promote sustainable utilization of waste materials.

The following materials were used in the present investigation:

1. Bitumen (60/70 Penetration Grade)
2. Coarse Aggregates
3. Fine Aggregates
4. Quarry Dust (Mineral Filler)
5. Waste PET Plastic
6. Crumb Rubber

Table 2.1 Materials Used in the Study

Sr. No.	Material	Purpose
1	Bitumen	Binding Material
2	Coarse Aggregate	Structural Skeleton
3	Fine Aggregate	Void Filling
4	Quarry Dust	Mineral Filler
5	PET Plastic	Modifier
6	Crumb Rubber	Modifier

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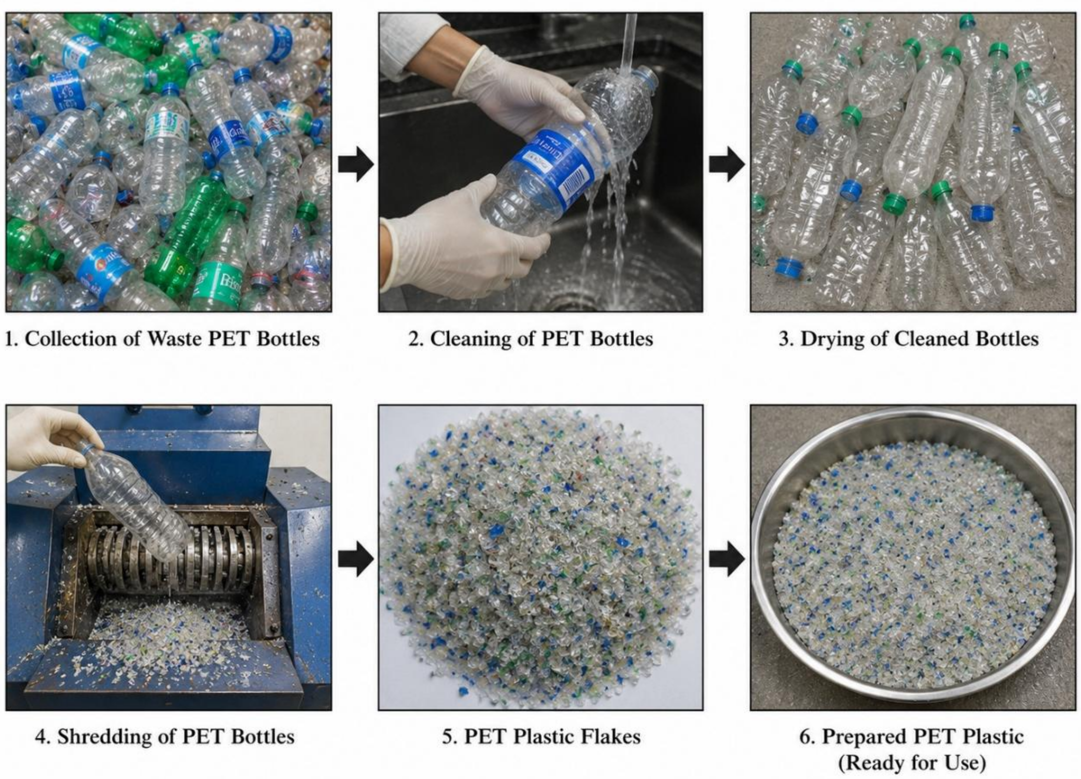


Figure 2.1 PET Plastic Preparation

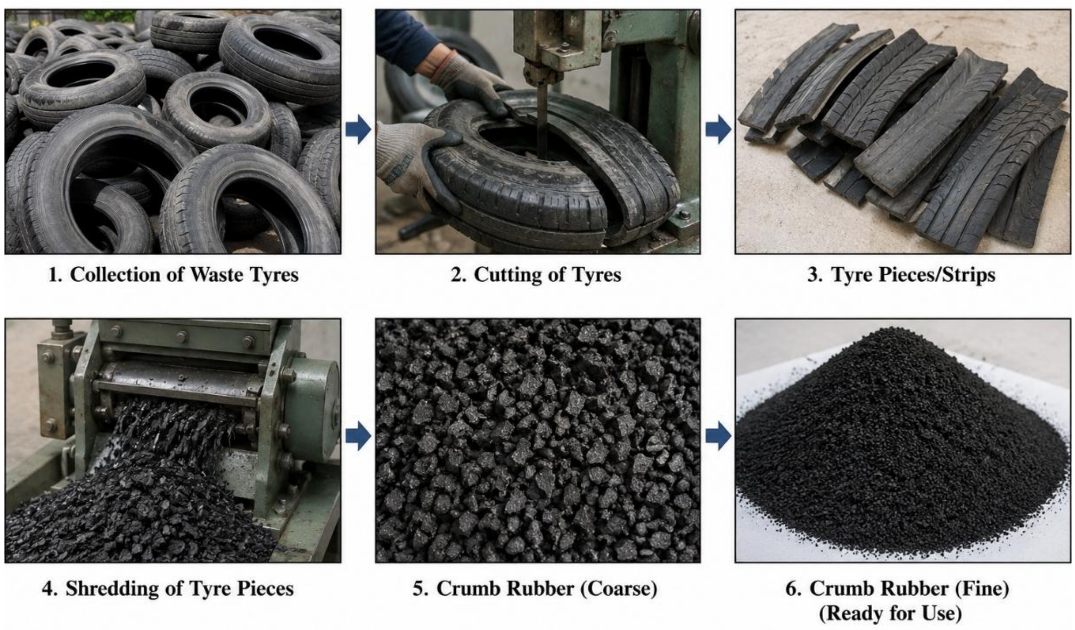


Figure 2.2 Crumb Rubber Preparation

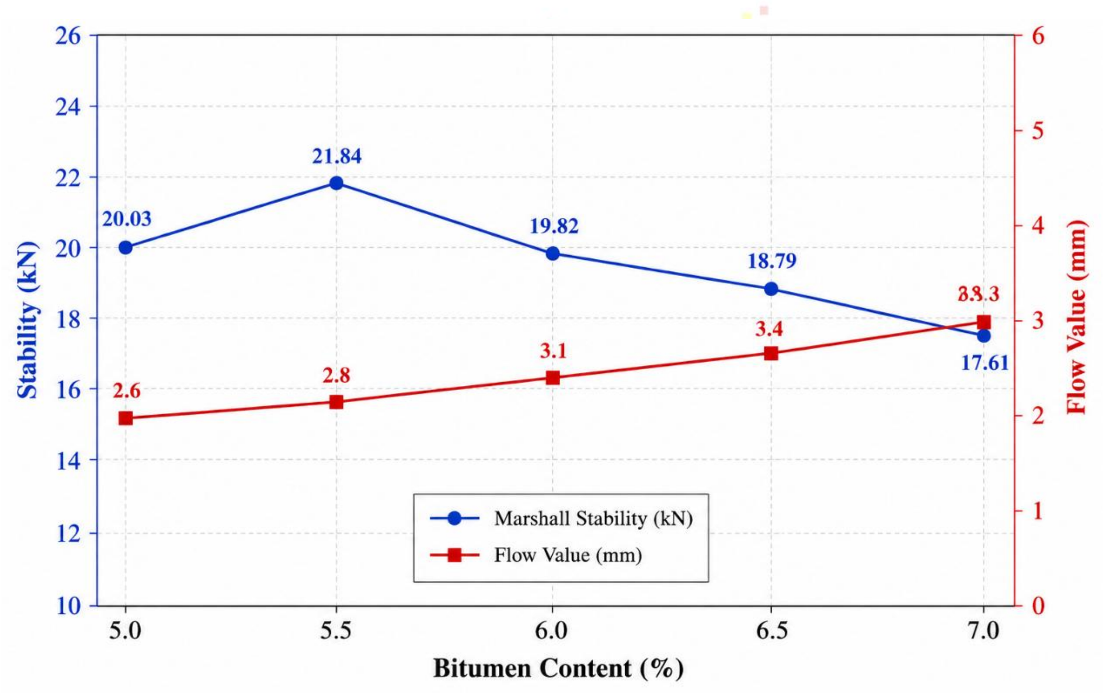
Modifier Contents Used:

Modifier	Percentage (%)
PET Plastic	3, 4.5, 6, 7.5, 9
Crumb Rubber	3, 4.5, 6, 7.5, 9

III. RESEULTS AND DISCUSSION

Table 3.1 Marshall Stability and Flow Values for Control Mix

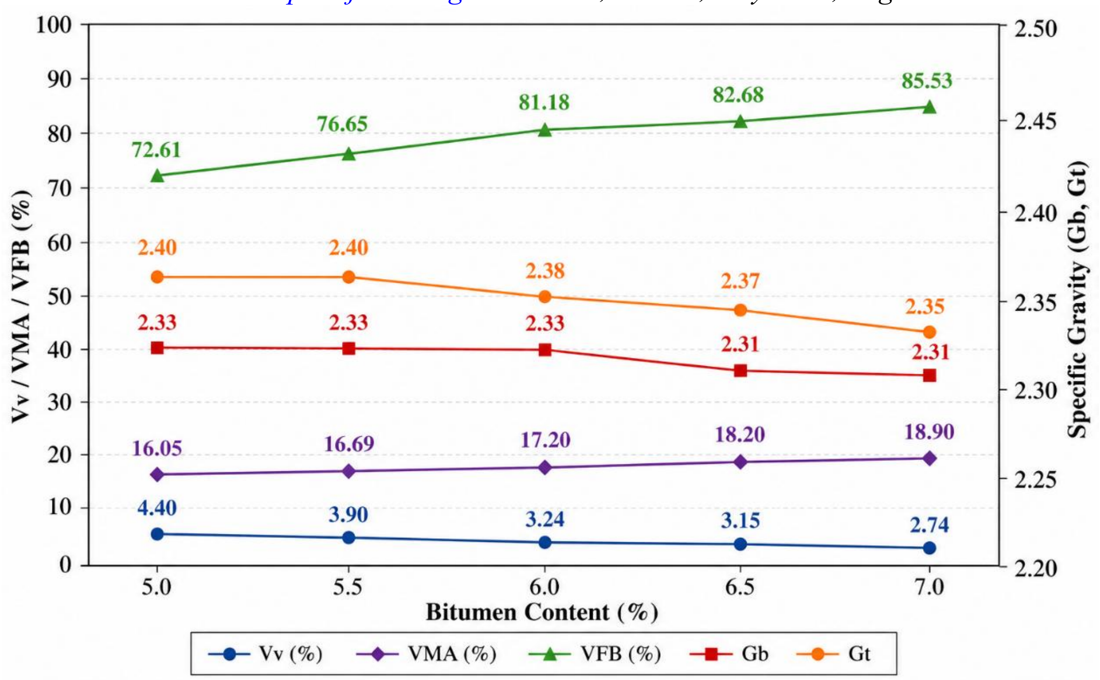
Bitumen Content (%)	Flow Value (mm)	Stability (kN)
5.0	2.6	20.03
5.5	2.8	21.84
6.0	3.1	19.82
6.5	3.4	18.79
7.0	3.8	17.61



Graph 3.1 Marshall Stability and Flow Values for Control Mix

Table 3.2 Density and Void Analysis for Control Mix

Bitumen (%)	Gb	Gt	Vv (%)	VMA (%)	VFB (%)
5.0	2.33	2.40	4.40	16.05	72.61
5.5	2.33	2.40	3.90	16.69	76.65
6.0	2.33	2.38	3.24	17.20	81.18
6.5	2.31	2.37	3.15	18.20	82.68
7.0	2.31	2.35	2.74	18.90	85.53



Graph 3.2 Density and Void Analysis for Control Mix

Table 3.3 Determination of OBC

Criterion	Bitumen Content (%)
Maximum Stability	5.5
Maximum Density	5.0
4% Air Voids	5.4

Average OBC:
[OBC = {5.5 + 5.0 + 5.4}/{3}]
[OBC = 5.1%]
Thus, the **Optimum Binder Content (OBC) was determined as 5.1%**.

At OBC:

1. Stability = 21.84 kN
2. Flow Value = 3.4 mm
3. VFB = 76.58%

These values satisfy MoRTH specifications.

Table 3.4 Marshall Stability and Flow Values for PET Modified Mix

PET Content (%)	Flow Value (mm)	Stability (kN)
3.0	2.4	22.82
4.5	2.5	22.07
6.0	3.0	23.00
7.5	4.4	21.53
9.0	4.5	21.33

Table 3.5 Marshall Stability and Flow Values for Crumb Rubber Modified Mix

Crumb Rubber (%)	Flow Value (mm)	Stability (kN)
3.0	2.23	20.14
4.5	2.50	21.57
6.0	3.00	22.64
7.5	4.80	21.47
9.0	4.17	18.00

Table 3.6 Comparison of Optimum Results

Mix Type	Optimum Modifier (%)	Stability (kN)	Flow (mm)
Conventional Mix	--	21.84	3.40
PET Modified Mix	6%	23.00	3.00
Crumb Rubber Mix	6%	22.64	3.00

CONCLUSION

The present experimental investigation was carried out to evaluate the performance of conventional bituminous concrete mixes and modified bituminous concrete mixes incorporating waste PET plastic and crumb rubber as sustainable modifiers. Marshall Mix Design was successfully performed for conventional Bituminous Concrete (BC) mixes using bitumen contents ranging from 5% to 7%, and the Optimum Binder Content (OBC) was determined as 5.1% based on Marshall Stability, bulk density, and 4% air void criteria. The conventional mix exhibited a maximum Marshall Stability of 21.84 kN, while all Marshall parameters, including flow value and Voids Filled with Bitumen (VFB), satisfied the requirements specified by MoRTH. Modified bituminous mixes were prepared by incorporating waste PET plastic and crumb rubber at proportions of 3%, 4.5%, 6%, 7.5%, and 9% by weight of bitumen. The experimental results revealed that Marshall Stability increased with increasing modifier content up to an optimum level and subsequently decreased due to excessive modifier concentration and reduced homogeneity within the mix. The highest Marshall Stability values of 23.00 kN and 22.64 kN were obtained for 6% PET plastic and 6% crumb rubber, respectively, indicating that 6% is the optimum modifier content for both materials. The incorporation of waste PET plastic significantly improved pavement stiffness, aggregate-bitumen bonding, and resistance to permanent deformation, whereas crumb rubber enhanced the flexibility, elasticity, and overall resilience of the bituminous mix. Among the two modifiers investigated, PET plastic exhibited superior performance in terms of Marshall Stability and overall engineering characteristics. The study further demonstrated that modified bituminous mixes performed better than conventional mixes and have the potential to increase pavement service life while reducing maintenance requirements. The utilization of waste PET bottles and discarded automobile tyres in road construction provides an environmentally sustainable solution for effective solid waste management, minimizes environmental pollution associated with plastic and tyre disposal, conserves natural resources, and promotes circular economy principles. Overall, the findings confirm that waste PET plastic and crumb rubber can be successfully utilized as alternative bitumen modifiers for sustainable pavement construction, with 6% PET plastic modification providing the most effective and economical performance among all the mixes evaluated in the present investigation.

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