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Performance Evaluation of Semi-Dense Bituminous Macadam with Crumb Rubber Modified Bitumen

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Abstract

This research focuses on evaluating the performance behavior of Semi-Dense Bituminous Macadam (SDBM) mixes incorporating 9% Crumb Rubber Modified Bitumen (CRMB), with varying proportions of bitumen binder. The aim is to understand how different binder contents influence critical pavement properties such as Marshall stability, flow value, bulk density, air voids, Voids in Mineral Aggregate (VMA), and Voids Filled with Bitumen (VFB). The experimental investigation reveals that increasing the bitumen content generally improves the mix's stability, flow, and bulk density up to a certain optimal level. The best performance was achieved at a bitumen content of 5.0%, where the mix recorded a maximum Marshall stability of 693 kg and a flow value of 3.15 mm. These values reflect a well-balanced mix with adequate strength and flexibility. However, increasing the bitumen content beyond this point led to a marginal drop in stability, accompanied by higher VFB and lower air voids, indicating a denser mix that might compromise long-term durability under heavy traffic or thermal stress. Based on the results, the optimal binder content lies between 5.0 and 5.25%, offering a favorable combination of mechanical strength, durability, and resistance to deformation. The addition of CRMB significantly enhances the overall performance of the pavement mix by improving elasticity and reducing susceptibility to cracking and rutting. Moreover, utilizing crumb rubber derived from waste tires supports sustainable infrastructure practices, offering an eco-friendly solution for waste management while improving pavement quality. This study provides meaningful insights into the effective use of CRMB in road construction, encouraging the development of resilient, long-lasting, and sustainable pavements. The findings serve as a valuable reference for civil engineers, highway authorities, and researchers involved in pavement material design and sustainable construction technologies.

Keywords: Semi-dense bituminous macadam, crumb rubber modified bitumen, marshal stability, Air voids, VMA, VFB, sustainable pavement

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INTRODUCTION

The growing demand for sustainable infrastructure has led to the exploration of innovative materials in road construction. Crumb Rubber Modified Bitumen (CRMB) offers a promising solution by incorporating waste rubber into bituminous mixtures. CRMB improves pavement durability, reduces maintenance costs, and mitigates environmental impacts by recycling scrap rubber. Semi-Dense Bituminous Macadam (SDBM) is a commonly used intermediate layer in flexible pavements, providing strength and resilience. This study focuses on evaluating the performance of SDBM with 9% CRMB at varying bitumen content levels to identify the optimal mix design. Key parameters such as Marshall stability, flow value, bulk density, air voids, VMA, and VFB are analyzed to determine the mixture's structural integrity and durability.

OBJECTIVES

The objective of this study is to evaluate the performance characteristics of Semi-Dense Bituminous Macadam (SDBM) using Crumb Rubber Modified Bitumen (CRMB) as a binder modifier. It aims to assess the impact of varying bitumen content on Marshall stability, flow value, bulk density, air voids, Voids in Mineral Aggregate (VMA), and Voids Filled with Bitumen (VFB). Additionally, the study seeks to identify the optimal bitumen content that ensures maximum strength, durability, and structural stability. By promoting the utilization of waste rubber in pavement design, this research supports sustainable construction practices and offers practical solutions for enhancing road performance and longevity.

MATERIAL

Aggregates

Aggregates used in the surface course must withstand high loads, abrasion, and wear from traffic. They should possess sufficient strength to resist crushing and be durable enough to endure the abrasive effects of vehicle movement. Suitable aggregates typically have a high specific gravity, indicating lower porosity, although moderate porosity is beneficial for better bitumen binding. Additionally, aggregates should exhibit appropriate granularity, determined through sieve analysis, with minimal flaky or elongated particles that may compromise structural integrity. Aggregates are broadly classified into two categories: coarse aggregates and fine aggregates. Coarse aggregates provide structural stability, while fine aggregates fill voids and enhance cohesion within the mixture [1–3].

Bitumen

Bitumen is available in various forms and grades, with paving-grade asphalt commonly used for road and airbase pavement construction. Commercial grades of bitumen are often applied in waterproofing structures and industrial flooring. In India, paving bitumen is classified into two types: A-type (sourced from Assam petroleum) and S-type (derived from other sources). The selection of bitumen grade is generally determined by tests such as penetration, ductility, and softening point tests, alongside flash and fire point assessments and specific gravity evaluations. For this study, S-type bitumen of 60/70 grade was utilized [4–6].

Crumb Rubber Modified Bitumen (CRMB)

CRMB is produced through a wet interaction process, where powdered scrap rubber is mixed with hot bitumen and mechanically agitated until a chemical reaction occurs between the bitumen and rubber particles. This modification enhances the durability and resilience of the bitumen, offering a cost-effective solution to common road issues like raveling, undulations, rutting, bleeding, and potholes [7–9].

For this research, scrap rubber was sourced from heavy vehicle tires, which were partially devulcanized and chemically treated. The rubber was obtained from Bharat Tire-Remolding in Bhopal. The study aims to evaluate the preparation of CRMB and its effect on the performance characteristics of bitumen. Using waste materials like rubber as a modifier contributes to environmental sustainability by repurposing non-biodegradable waste [10–12].

Filler

Cement was used as a filler material in this study. A 2% cement powder by weight of the aggregate was added to enhance the binding properties of the mixture, contributing to the overall strength and durability of the pavement.

RESULTS

Table 1 presents the properties of Semi-Dense Bituminous Macadam (SDBM) with 9% Crumb Rubber Modified Bitumen (CRMB) and varying percentages of bitumen binder. The results are analyzed to assess

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Table 1. Characteristics of SDBM with 9% CRMB & varying percentage of bitumen binder.

S.N.	Bitumen (%)	Weight of sample (gm)		Marshal stability (kg)	Flow value (mm)	Bulk density (gm/cc)	Air Voids (%)	VMA (%)	VFB (%)
		Air	*Water*						
1.	4.5	1198	655	1230	2.58	2.19	4.83	13.46	65.58
2.	4.75	1186	675	1275	2.86	2.24	4.56	13.93	68.23
3.	5	1194	693	1320	3.15	2.32	4.18	14.37	70.72
4.	5.25	1176	690	1360	3.39	2.38	4.07	14.82	72.94
5.	5.5	1183	682	1335	3.57	2.30	3.89	15.17	73.89

the impact of bitumen content on key performance parameters including Marshall stability, flow value, bulk density, air voids, Voids in Mineral Aggregate (VMA), and Voids Filled with Bitumen (VFB) (Table 1) [13–15].

Marshall Stability and Flow Value

The Marshall stability values demonstrate an increasing trend with the increase in bitumen content, peaking at 5.0% bitumen with a stability value of 693 kg. Beyond this point, stability slightly decreases. Similarly, the flow value increases with the bitumen content, suggesting improved deformation resistance. However, excessive flow beyond the optimum bitumen content may lead to reduced structural integrity [16].

Bulk Density

Bulk density also increases with higher bitumen content, with the maximum density of 2.38 gm/cc at 5.25% bitumen. This indicates effective compaction and bitumen coating, contributing to enhanced load-bearing capacity.

Air Voids and Voids in Mineral Aggregate (VMA)

Air voids gradually reduce with increasing bitumen content, indicating better filling of voids. The lowest air void content of 3.89% is observed at 5.5% bitumen, which may reduce permeability and increase durability. VMA values increase with bitumen content, with a peak of 15.17% at 5.5% bitumen, ensuring adequate bitumen presence for durability [17].

Voids Filled with Bitumen (VFB)

The Voids Filled with Bitumen (VFB) metric demonstrates a steady rise with the increase in bitumen content within the mix. This indicates that a greater proportion of the aggregate voids are being effectively filled with the bituminous binder, resulting in a denser and more cohesive pavement structure. At a bitumen content of 5.5%, the VFB value peaks at 73.89%, suggesting the mix has achieved a high level of saturation and compactness. Such a condition is generally associated with improved durability, reduced permeability, and enhanced resistance to the ingress of moisture, all of which contribute positively to the longevity and performance of the pavement.

Upon analyzing the test data and plotted results, it was observed that the maximum Marshall stability was achieved at 5.25% binder content when using 9% Crumb Rubber Modified Bitumen (CRMB). This is in contrast to the 5.5% binder content required in conventional mixes using unmodified bitumen. These findings clearly indicate that CRMB enhances the mechanical strength of the mixture, allowing for a reduction in the total bitumen required to achieve optimal performance. The use of CRMB not only maintains the integrity and strength of the mix but also supports more economical and sustainable use of materials by reducing binder consumption. To determine the most suitable binder content for achieving the best overall performance, several graphical analyses were conducted. These include:

- *Binder content vs. Marshall stability (Figure 1):* Demonstrates how stability varies with binder content, helping to pinpoint the percentage that offers maximum load-bearing capacity.

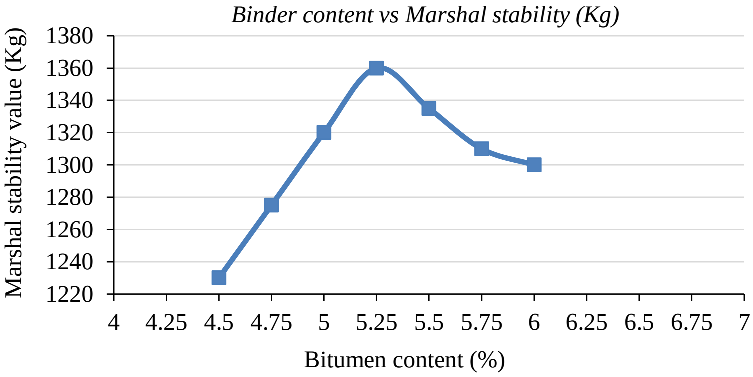

Figure 1. Bitumen % vs. Marshall stability value.

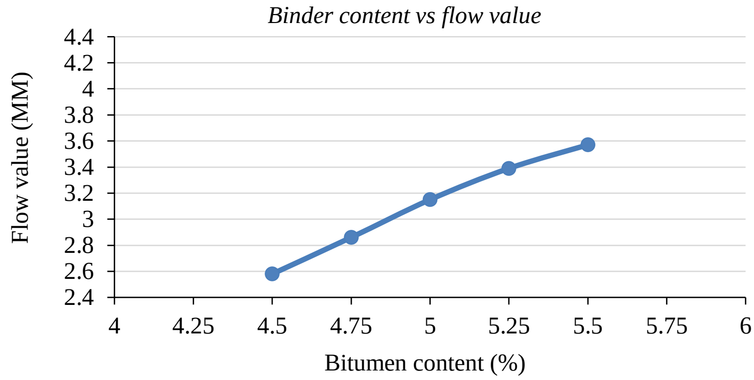

Figure 2. Bitumen % vs. flow value.

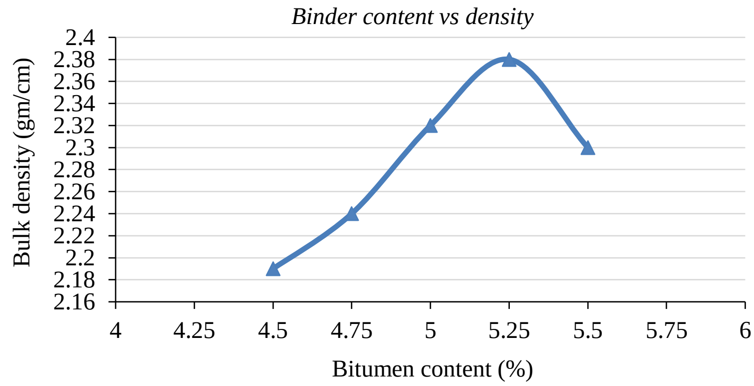

Figure 3. Bitumen % vs. density.

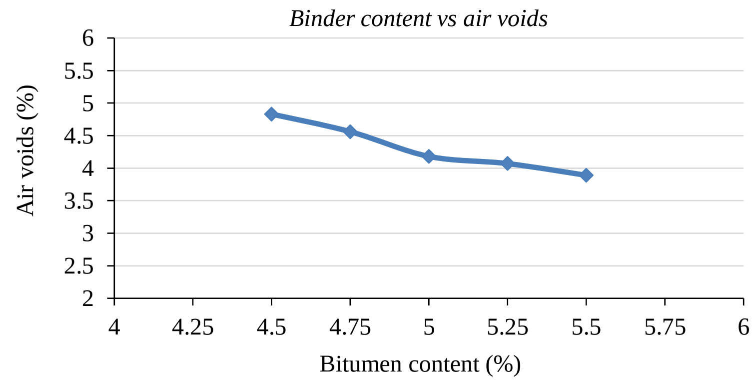

Figure 4. Bitumen % vs. air voids %.

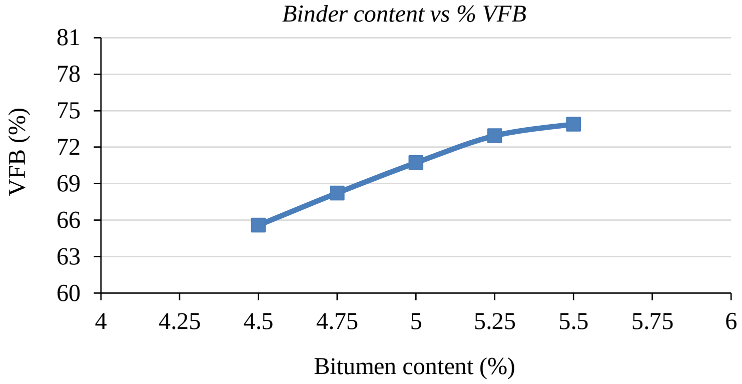

Figure 5. Bitumen % vs. voids filled with bitumen % (VFB).

- *Binder content vs. flow value (Figure 2):* Indicates the flexibility and deformation response of the mix under load.
- *Binder content vs. bulk density (Figure 3):* Reflects the compactness of the mix and its ability to resist displacement.
- *Binder content vs. air voids (Figure 4):* Shows the proportion of empty spaces, essential for understanding permeability and potential moisture damage.
- *Binder content vs. voids filled with bitumen (VFB) (Figure 5):* Illustrates how effectively the available voids in the mineral aggregate are filled by the bitumen, contributing to the mixture's overall performance.

These graphical interpretations aid in identifying the optimum binder content, ensuring a balance between strength, flexibility, and durability. The incorporation of Crumb Rubber Modified Bitumen (CRMB) thus proves to be an effective strategy not only for enhancing pavement performance but also for promoting environmentally responsible construction practices by repurposing waste rubber in a productive and sustainable manner.

CONCLUSION

The findings of this research indicate that incorporating 9% CRMB in SDBM significantly enhances the pavement's performance characteristics. The optimal bitumen content range was determined to be between 5.0 and 5.25%, offering the highest Marshall stability and balanced void properties. CRMB-modified mixtures exhibited increased durability, reduced air voids, and improved load-bearing capacity. Additionally, the use of waste rubber as a modifier contributes to environmental sustainability and cost-effective road construction. These results provide a robust framework for implementing CRMB in practical road construction projects, supporting the development of resilient and sustainable pavement systems.

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