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Performance Evaluation of Rubber Crumb-Modified Bitumen for Sustainable Pavement Applications

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Abstract

This research investigates the effect of rubber crumb modification on the physical and mechanical properties of VG-40 bitumen for flexible pavement applications. Rubber crumbs were incorporated at varying percentages (0, 8, 10, 12, 14, and 16%) to analyze their impact on penetration, softening point, ductility, and elastic recovery. Additionally, the Marshall stability test was conducted to evaluate the strength and deformation characteristics of the bitumen mix. The results demonstrated a significant reduction in penetration values, indicating increased hardness and stiffness with higher rubber crumb content. The softening point increased from 53 to 64°C, showcasing improved thermal resistance. Ductility and elastic recovery decreased with the addition of rubber crumbs, reflecting reduced flexibility and resilience. The highest Marshall stability of 15.89 kN was observed at 5.4% bitumen content, establishing it as the optimum bitumen content for maximum load-bearing capacity. Overall, rubber crumb-modified bitumen exhibited enhanced durability, stability, and resistance to deformation, making it a suitable choice for sustainable pavement construction. The utilization of waste rubber crumbs also promotes eco-friendly construction practices, reducing environmental impact.

Keywords: Rubber crumb, bitumen modification, VG-40 Bitumen, flexible pavement, Marshall stability, sustainable construction, penetration test, softening point, elastic recovery, ductility

INTRODUCTION

The increasing demand for durable and sustainable road infrastructure has necessitated the exploration of alternative materials in pavement construction. One promising approach is the modification of bitumen using waste rubber crumbs derived from discarded tires. Rubber crumb-modified bitumen enhances the performance of flexible pavements by improving its resistance to deformation, thermal cracking, and fatigue. This modification also provides an eco-friendly solution by recycling waste rubber, thereby reducing landfill waste and promoting sustainable construction practices [1–4].

In this study, VG-40 grade bitumen was modified with rubber crumbs at varying percentages (0, 8, 10, 12, 14, and 16%) to evaluate its physical and mechanical properties. Key tests, including penetration, softening point, ductility, and elastic recovery, were conducted to assess the effects of rubber crumb incorporation. Additionally, the Marshall stability test was performed to determine the optimal bitumen content for achieving maximum stability and durability. The findings from this research will provide valuable insights into the suitability of rubber crumb-modified bitumen for flexible pavement applications, particularly in regions experiencing heavy traffic and extreme temperatures [5–7].

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OBJECTIVES

The primary objective of this research is to evaluate the impact of rubber crumb modification on the physical and mechanical properties of VG-40 bitumen for flexible pavement applications. By incorporating varying percentages of rubber crumbs (0, 8, 10, 12, 14, and 16%), the study aims to assess changes in penetration, softening point, ductility, and elastic recovery to determine the material's stiffness, thermal resistance, and flexibility. Additionally, the Marshall stability test is conducted to establish the optimal bitumen content that ensures maximum stability, durability, and load-bearing capacity. The research also focuses on analyzing the suitability of rubber crumb-modified bitumen for use in regions with heavy traffic and extreme temperatures. Furthermore, the study promotes sustainable construction practices by encouraging the recycling of waste rubber crumbs, contributing to environmentally friendly pavement solutions [8–11].

MATERIALS

The materials used in this study include VG-40 grade bitumen, rubber crumbs, and aggregates for the Marshall stability test. Each material was carefully selected to ensure compatibility and adherence to relevant standards for pavement construction [12].

VG-40 Grade Bitumen

VG-40 bitumen, commonly used in high-traffic and heavy-load areas, was used as the base binder. It offers enhanced resistance to deformation and rutting, making it suitable for flexible pavements [13].

Rubber Crumbs

Rubber crumbs were obtained from waste tires and used as a bitumen modifier. These crumbs, sized between 0.3 and 1 mm, were incorporated at varying percentages (0, 8, 10, 12, 14, and 16%) by weight of bitumen. The addition of rubber crumbs improves the bitumen's stiffness, elasticity, and resistance to thermal and load-induced deformation [14].

Aggregates

Coarse and fine aggregates conforming to standard pavement construction specifications were used for the preparation of Marshall specimens. The aggregates were carefully graded to achieve the desired mix properties [15].

Filler Material

Stone dust was used as a filler material to enhance the bond between the bitumen and aggregates. It aids in improving the stability and durability of the mix.

Water

Potable water was used during sample preparation, ensuring consistency and reliability of the results.

RESULTS

Penetration Test Results

The penetration test was conducted to evaluate the hardness of bitumen with the addition of rubber crumbs at various percentages. The results are summarized in Table 1.

The penetration values indicate a clear reduction in the softness of bitumen with the increasing percentage of rubber crumbs. VG-40 bitumen exhibited the highest penetration value of 47 (1/10 mm), representing its comparatively softer nature. As rubber crumbs were incorporated into the bitumen, the penetration values gradually decreased [16].

At 8% rubber crumbs, the penetration reduced to 42 (1/10 mm), reflecting a marginal increase in stiffness. With further increments, the penetration values showed a consistent decline, reaching 32 (1/10 mm) at 16% rubber crumbs. This trend demonstrates that the addition of rubber crumbs enhances the hardness and rigidity of the bitumen (Figure 1) [17].

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Table 1. Penetration test results.

Penetration (1/10 mm)	
Rubber Crumbs %	***Values***
0	47
8%	42
10%	40
12%	38
14%	35
16%	32

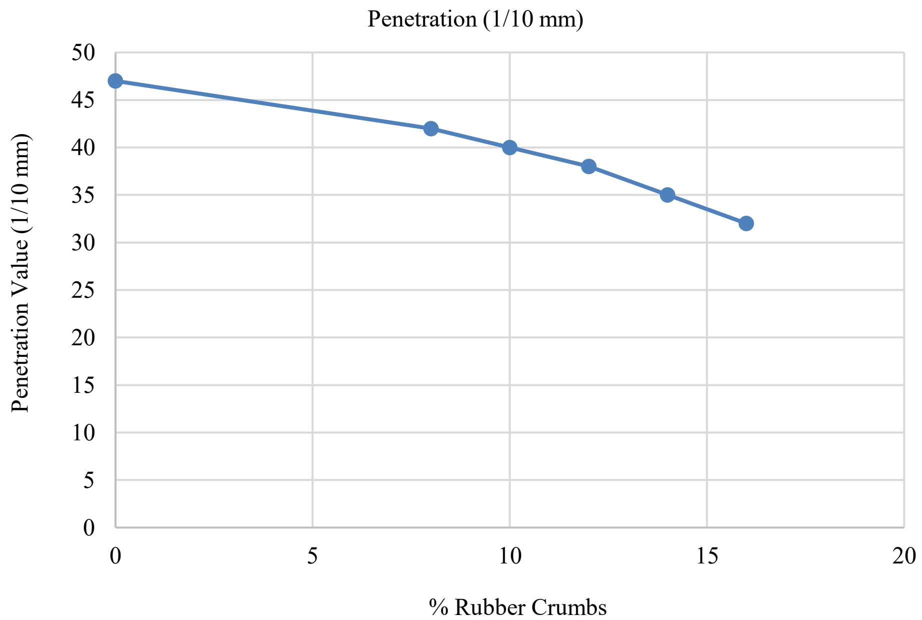

Figure 1. Effect of rubber crumb percentage on bitumen penetration.

The reduction in penetration can be attributed to the rubber crumbs acting as a reinforcing material, restricting the deformation under applied loads. This characteristic makes the modified bitumen more suitable for applications in regions experiencing higher traffic loads and elevated temperatures.

Overall, the results suggest that incorporating rubber crumbs in the range of 8 to 16% can effectively improve the hardness and durability of bitumen, contributing to enhanced performance in flexible pavement construction.

Marshall Test Results

The Marshall stability test was conducted to evaluate the strength and deformation characteristics of bitumen with varying bitumen content. The results are presented in Table 2.

The Marshall Properties test results for VG-40 grade bitumen indicate the effect of bitumen content on key parameters such as stability, unit weight, flow, air voids (VA), voids in mineral aggregate (VMA), and voids filled with bitumen (VFB). The observations from the results are discussed below:

Stability

Stability is a measure of the load-bearing capacity of the bituminous mix. The results show an increasing trend in stability from 13.92 kN at 4.8% bitumen content to a peak of 15.89 kN at 5.4%, after which stability decreases. This suggests that 5.4% bitumen content provides the highest resistance to deformation, making it the optimal content for stability.

Table 2. Test results of Marshall properties with VG-40 grade bitumen.

Bitumen Content (%)	Stability (kN)	Unit Wt (gm/cc)	Flow (mm)	VA (%)	VMA (%)	VFB (%)
4.8	13.92	2.351	2.5	5.29	15.52	65.9
5.1	15.2	2.354	3.1	4.75	15.68	69.73
5.4	15.89	2.355	3.5	4.27	15.9	72.25
5.7	15.66	2.353	3.7	3.93	16.25	75.79
6	15.19	2.351	3.9	3.57	16.57	78.48

Unit Weight

The unit weight of the mixture remains nearly constant across the bitumen content range, fluctuating slightly between 2.351 and 2.355 g/cm^3. This indicates that the variation in bitumen content does not significantly affect the overall density of the mix.

Flow

Flow values indicate the mix's ability to deform under loading. The results show a progressive increase in flow with increasing bitumen content, ranging from 2.5 mm at 4.8% bitumen to 3.9 mm at 6% bitumen. This suggests that higher bitumen content results in greater deformation, which may impact the mix's resistance to rutting.

Air Voids (VA)

Air voids represent the amount of air trapped in the compacted mix. The values decrease with increasing bitumen content, from 5.29% at 4.8% to 3.57% at 6%. This indicates that increasing bitumen content leads to a denser mix, reducing air voids.

Voids in Mineral Aggregate (VMA)

VMA represents the total volume of void spaces in the aggregate structure. The values range from 15.52% at 4.8% to 16.57% at 6%, showing a gradual increase. This suggests that more bitumen is filling the aggregate voids, which is beneficial for durability.

Voids Filled with Bitumen (VFB)

VFB represents the percentage of VMA filled with bitumen. The values increase from 65.9% at 4.8% to 78.48% at 6%, indicating that a higher bitumen content leads to more voids being occupied by bitumen, which enhances durability but may reduce skid resistance if excessive.

The analysis of the Marshall Properties suggests that 5.4% bitumen content provides the best balance between stability and durability, making it the optimal choice for road construction. While higher bitumen content improves flow and VFB, excessive bitumen beyond 5.4% leads to a reduction in stability, which may negatively impact performance under heavy traffic conditions.

CONCLUSION

This study evaluated the effect of rubber crumb modification on the physical and mechanical properties of VG-40 bitumen for flexible pavement applications. The results demonstrated that incorporating rubber crumbs significantly enhanced the bitumen's hardness and thermal resistance, as indicated by reduced penetration values and increased softening points. While ductility and elastic recovery decreased with higher rubber crumb content, the stability of the bitumen mix improved, reaching an optimal value of 15.89 kN at 5.4% bitumen content. Beyond this, excess bitumen reduced stability, highlighting the need for careful mix design. The study concludes that rubber crumb-modified bitumen offers enhanced durability and resistance to deformation, making it a sustainable and cost-effective choice for road construction, especially in regions with heavy traffic and high temperatures.

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