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A Comprehensive Review of the Influence of Crumb Rubber Content on Bituminous Binders and Mixes

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ABSTRACT

The rapid growth of the automobile industry has led to the accumulation of large quantities of waste tires, creating significant environmental challenges worldwide. One effective solution for recycling waste tires is the incorporation of crumb rubber (CR) into bituminous binders and asphalt mixtures used in road construction. Crumb rubber modification improves the engineering properties of asphalt pavements by enhancing resistance to rutting, fatigue cracking, thermal cracking, and moisture damage. The performance of crumb rubber modified bitumen (CRMB) is highly influenced by the percentage of crumb rubber added to the binder. Various studies have demonstrated that increasing crumb rubber content generally improves elasticity, stiffness, viscosity, and durability of asphalt mixtures; however, excessive rubber content may adversely affect workability and construction operations. This review paper presents a comprehensive analysis of the influence of crumb rubber content on the physical, rheological, mechanical, and durability characteristics of bituminous binders and asphalt mixtures. The paper also discusses the benefits, challenges, environmental implications, and future research directions associated with crumb rubber modified asphalt technology.

Keywords — Crumb Rubber, Bituminous Binder, Asphalt Mixtures, Waste Tire Recycling, Crumb Rubber Modified Bitumen, Pavement Performance, Sustainable Pavements, Rutting Resistance.

1. Introduction

Road transportation infrastructure plays a vital role in economic development and social connectivity. Flexible pavements constructed using bituminous materials constitute the majority of road networks worldwide due to their cost-effectiveness, ease of construction, and maintenance advantages. However, increasing traffic loads, heavy axle loads, and extreme climatic conditions often lead to pavement distresses such as rutting, fatigue cracking, thermal cracking, and moisture-induced damage.

Simultaneously, the disposal of end-of-life tires has emerged as a major environmental concern. Millions of waste tires are generated annually, occupying valuable landfill space and creating potential fire and health hazards. Recycling waste tires into crumb rubber for use in asphalt pavements has gained significant attention as an environmentally sustainable and economically viable solution.

Crumb rubber is produced by mechanically grinding waste tires into small particles. These particles are incorporated into bitumen either through the wet process, where rubber is blended with the binder before mixing, or through the dry process, where rubber particles are added directly to the aggregate mixture. The interaction between crumb rubber and bitumen alters the rheological behavior of the binder and improves pavement performance characteristics.

The effectiveness of crumb rubber modification depends largely on the crumb rubber content used in the mixture. Therefore, understanding the influence of crumb rubber dosage on binder and mixture properties is essential for optimizing pavement design and performance. This review aims to provide a detailed assessment of the effects of crumb rubber content on bituminous binders and asphalt mixtures.

2. Crumb Rubber Modified Bitumen (CRMB)

Crumb Rubber Modified Bitumen (CRMB) is a type of modified binder produced by blending processed rubber particles obtained from waste tyres with conventional bitumen at elevated temperatures. The incorporation of crumb rubber alters the physical and chemical properties of bitumen, resulting in improved performance characteristics suitable for flexible pavement applications [7].

The production of crumb rubber involves mechanical shredding and grinding of waste tyres into fine particles of specific sizes. These rubber particles are free from steel and fiber components and are categorized based on their gradation. The crumb rubber is then mixed with hot bitumen, typically at temperatures ranging between 160°C and 180°C, allowing the rubber particles to interact with the bitumen matrix. During this process, the rubber absorbs lighter fractions of bitumen and swells, forming a gel-like structure that enhances the binder properties.

CRMB offers several advantages over conventional bitumen. It improves the elasticity and flexibility of the binder, enabling pavements to withstand heavy traffic loads and resist cracking. The enhanced viscosity of CRMB provides better resistance to rutting and deformation, especially under high-temperature conditions. Additionally, CRMB exhibits improved fatigue resistance, which contributes to longer pavement life and reduced maintenance costs.

Another significant benefit of CRMB is its superior resistance to aging and oxidation. The presence of rubber particles slows down the hardening process of bitumen, thereby maintaining its performance characteristics over time. Moreover, CRMB demonstrates better adhesion with aggregates, resulting in improved bonding and reduced stripping in the presence of moisture.

From an environmental perspective, CRMB plays a vital role in sustainable development by promoting the recycling of waste tyres. It reduces the environmental hazards associated with tyre disposal and contributes to resource conservation. Economically, the use of CRMB can lower overall lifecycle costs of pavements due to its durability and reduced maintenance requirements.

However, the use of CRMB also presents certain challenges. Issues such as storage stability, phase separation, and increased mixing temperature need to be addressed for effective implementation. Proper design, quality control, and adherence to standards such as IS 15462 are essential to ensure the consistent performance of CRMB in pavement construction.

Crumb Rubber Modified Bitumen represents a promising solution for developing sustainable and durable flexible pavements. Its ability to enhance pavement performance while addressing environmental concerns makes it an important material in modern road construction practices.

3. Hazards of Tyre Waste

- Burning of waste tyres releases large amounts of carbon emissions and toxic gases, contributing to severe air pollution.
- The large volume of discarded tyres creates storage problems and occupies valuable land resources.
- Waste tyres may release harmful chemicals that can contaminate soil and water, especially under acidic conditions.
- Accumulated tyres often collect stagnant water, providing ideal breeding grounds for mosquitoes and increasing the risk of diseases.
- Tyre fires are extremely hazardous, releasing carbon fumes, hydrocarbons, and toxic residues into the atmosphere.
- Large tyre dumps pose environmental and health risks due to the formation of water pools and the spread of vector-borne diseases.
- Once tyre fires start, they are difficult to control and extinguish, causing long-term environmental damage.

Table 1: Materials/Waste Tyre Component

Materials	***Car***	***Lorry***	***OTR***
Rubber/ Elastomers	*46%*	*44%*	*46%*
Carbon Black (CB)	*22.5%*	*22.5%*	*21%*
Metals	*15.5%*	*25%*	*11%*
Textile	*6.5%*	*6.5%*	*11%*
ZnO	*1.5%*	*1.8%*	*1.8%*
Sulphur (S)	*0.8%*	*0.8%*	*0.8%*
Additional	*7.4%*	*5.5%*	*6.0%*
Total Carbon based materials	*75%*	*66%*	*74%*

Waste tyres can be processed into different forms such as whole tyres, shredded tyres, chipped tyres, ground rubber, or crumb rubber, depending on the intended application. In bituminous mixtures, rubber from waste tyres is commonly used in the form of rubber particles or granules.

The processing of waste tyres into usable material involves a two-stage size reduction process. Initially, the tyres are cut into smaller pieces, followed by further shredding or grinding to obtain rubber particles of desired sizes. During this process, unwanted components such as steel wires and textile fibers are removed through magnetic separation and screening operations. The final product obtained after processing is commonly referred to as rubber aggregate.

To improve the quality of the material, cleaning processes such as washing and surface treatment are carried out to remove dirt and impurities from the shredded rubber. The processed rubber particles are then sieved using standard screens to obtain uniform sizes. Typically, particles passing through a 22.4 mm sieve and retained on a 5.6 mm sieve are selected, depending on the mix design requirements.

These rubber aggregates are incorporated into bituminous mixes as a partial replacement for conventional aggregates, usually in the range of 10–20% by weight of the coarse aggregate. For effective mixing, the bituminous mixture is prepared at elevated temperatures, generally between 160°C and 170°C. The rubber particles are either blended directly with hot bitumen or mixed with heated aggregates before the addition of bitumen to ensure proper coating and uniform distribution.

Since waste tyres are thermoset materials, they do not melt when mixed with bitumen. Instead, they soften and interact with the bitumen matrix, improving certain properties such as elasticity, flexibility, and resistance to deformation. Large quantities of waste tyres are collected from roadsides, landfill sites, and scrap dealers. These tyres are sorted based on size and condition before processing. Proper classification and preparation of waste tyres are essential to ensure consistency in the final bituminous mix and to achieve the desired performance characteristics in road construction.

Table 2: Property of Bitumen: - VG 30 GRADE

	Specification	Test Method
Penetration at 25°C (0.1 mm)	46	IS 1203
Absolute Viscosity at 60°C (poises)	2300-3500	IS 1206(PART 2)
Kinematic viscosity at 135°C. Min	340	IS 1206 (part 3)
Flash & Fire Point °C, Min	220	IS 1448 (p:69)
Solubility in TCE Percent. Min	99.01	IS 1216
Softening point (R&D) °C Min	46	IS 1205
Test on build up from moving daint film oven test:		
a) Viscosity ratio at 60°C. Max	4.2	IS 1206(PART 2)
b) Ductility at 25°C Min.	40.2	IS 1208

Table 3: Properties of Crumb Rubber Modified Bitumen (CRMB) as per IS 15462: 2004

S. No.	Property	Test Method	CRMB 50	CRMB 55	CRMB 60
1	Penetration at 25°C (0.1 mm)	IS 1203	50–70	40–60	30–50
2	Softening Point (°C), Min	IS 1205	50	55	60
3	Elastic Recovery at 15°C (%), Min	IS 15462	50	50	50
4	Ductility at 27°C (cm), Min	IS 1208	50	40	25
5	Flash Point (°C), Min	IS 1209	220	220	220
6	Viscosity at 150°C (Poise)	IS 1206 (Part 2)	1500–3000	2000–4000	2500–5000
7	Separation Difference in Softening Point (°C), Max	IS 15462	4	4	4
8	Loss in Mass after RTFO Test (%), Max	IS 15462	1.0	1.0	1.0
9	Increase in Softening Point after RTFO (°C), Max	IS 15462	6	6	6

4. Literature Review

Researchers and teachers of structural design in this field have conducted many types of studies to discover ways to incorporate scrap elastic blends of bitumen into regular bitumen to further develop the properties of bitumen.

Sharma et al. (2025) investigated the effect of crumb rubber modification on the physical and mechanical properties of VG-40 bitumen. Rubber crumbs were added in varying proportions (0%, 8%, 10%, 12%, 14%, and 16%) to evaluate their influence on penetration, softening point, ductility, and elastic recovery. The results indicated a decrease in penetration values with increasing rubber content, signifying enhanced stiffness and hardness. The softening point increased from 53°C to 64°C, demonstrating improved resistance to high temperatures. However, ductility and elastic recovery decreased, indicating reduced flexibility. Marshall stability analysis revealed a maximum value of 15.89 kN at an optimum bitumen content of 5.4%. The study concluded that crumb rubber-modified bitumen improves durability and deformation resistance while promoting environmentally sustainable construction practices [8].

Phan et al. (2025) conducted a comparative analysis of four crumb rubber incorporation techniques: dry, wet, hybrid, and pelletized methods. Using PG 64–22 as the base binder and crumb rubber content ranging from 10% to 15%, the study evaluated rheological and mechanical properties through tests such as MSCR, IDEAL-CT, IDEAL-Rutting, dynamic modulus, and overlay testing. The findings revealed that 15% crumb rubber improved the binder grade to PG 76–22, with the hybrid method showing the best performance. The rutting factor ($G^*/\sin\delta$) increased to 3.47 kPa, and MSCR recovery improved significantly to 72%. Both hybrid and wet methods nearly doubled rutting resistance and enhanced cracking tolerance. Microscopic analysis using SEM and CT scanning confirmed uniform distribution of rubber particles, contributing to improved structural integrity and pavement performance [9].

Memon et al. (2025) focused on optimizing the performance of crumb rubber modified bitumen by analyzing blending parameters and material characteristics. The study evaluated the effects of temperature, mixing speed, blending time, and material types using a 40/60 penetration grade binder with 15% crumb rubber. Results showed that penetration decreased while softening point increased significantly, indicating improved stiffness. Optimal blending conditions were identified as high-shear mixing at 180°C for 90 minutes with a speed of 2000–3000 rpm. Statistical analysis confirmed the significant impact of blending parameters on CRMB performance, with regression models achieving a high predictive accuracy ($R^2 = 0.85$). The study emphasized that both process optimization and material selection are essential for producing stable and efficient CRMB [10].

Blab et al. (2024) examined the impact of crumb rubber on the physical and rheological properties of bitumen under varying climatic conditions. Using SUPERPAVE standards and finite difference modeling, the study assessed pavement performance in Malaysian regions. Experimental analysis using dynamic shear rheometer, rotational viscometer, and bending beam rheometer demonstrated that the addition of 15% crumb rubber significantly improved stiffness, temperature susceptibility, and aging resistance. ATR-FTIR analysis further confirmed enhanced durability and resistance to oxidative aging. The study concluded that crumb rubber modification improves pavement longevity while offering a sustainable solution for waste tyre management [11].

Wang et al. (2024) examined the use of wax-based additives in CRMB to enhance workability and optimize preparation procedures. The study analyzed the influence of additives and temperature on rubber–bitumen interaction through swelling tests and rheological characterization. Results indicated that wax additives reduce bitumen viscosity, thereby promoting better interaction between rubber and bitumen at lower temperatures. However, a significant portion of wax penetrated the rubber particles in warm-mix conditions. Although warm-produced CRMB reduces energy consumption, the study concluded that it cannot fully replace conventional hot-mix production due to performance limitations [12].

Albornoz et al. (2022) investigated the long-term ageing behavior of crumb rubber modified asphalt binders under real service conditions. The study evaluated samples from highways exposed to severe climatic and traffic conditions using Dynamic Shear Rheometer (DSR) testing. Rheological parameters such as complex modulus, phase angle, elastic recovery, and creep behavior were analyzed. The findings revealed that CRMB exhibits ageing characteristics comparable to conventional polymer modified bitumen. Additionally, differences were observed between laboratory-simulated ageing (RTFO and PAV tests) and real-field ageing, highlighting the importance of field-based evaluation [13].

5. Conclusion

Crumb rubber modification has emerged as an effective and sustainable approach for enhancing the performance of bituminous binders and asphalt mixtures while simultaneously addressing the environmental challenges associated with waste tire disposal. The incorporation of crumb rubber generally improves key binder properties such as stiffness, viscosity, elastic recovery, softening point, and rheological performance. In asphalt mixtures, appropriate crumb rubber content significantly enhances rutting resistance, fatigue life, thermal cracking resistance, and moisture durability. The extent of these improvements largely depends on the dosage of crumb rubber, with most studies identifying an optimum range of approximately 10–20% by weight of binder. While higher crumb rubber contents can further improve certain mechanical properties, they may also lead to increased viscosity, workability issues, and production challenges. Overall, crumb rubber modified asphalt offers substantial environmental, economic, and engineering benefits, making it a promising solution for sustainable pavement construction. Continued research and technological advancements are expected to further optimize crumb rubber utilization and expand its application in future transportation infrastructure.

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