



Utilization of Waste Rubber in Road Construction Using Crumb Rubber Modified Bitumen

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Abstract:

The rapid increase in vehicular population has significantly raised waste tyre generation, leading to environmental issues due to their non-biodegradable nature and improper disposal methods like landfilling and open burning. This study explores the use of waste rubber in road construction as a sustainable solution. Waste tyres are processed into crumb rubber and incorporated into bituminous mixes to produce Crumb Rubber Modified Bitumen (CRMB). Different methods—wet, dry, and hybrid—are analyzed for their effectiveness. Experimental tests such as hardness, compression set, adhesion, and resistance to liquids are conducted to evaluate material properties.

Results show that crumb rubber improves pavement elasticity, durability, and resistance to rutting and cracking. Rubberized roads perform better under heavy traffic and varying climatic conditions, while also offering improved skid resistance and reduced noise. Although initial costs are slightly higher, lower maintenance and longer service life make it cost-effective. Overall, the use of waste rubber in road construction promotes sustainable infrastructure and effective waste management, making CRMB a promising eco-friendly alternative.

Keywords:

Waste Tyers, Crumb Rubber Modified Bitumen (CRMB), Sustainable Road Construction, Recycling, Pavement Performance, Bitumen Modification

1. INTRODUCTION

The rapid growth of the transportation sector has resulted in a significant increase in vehicular population worldwide, leading to the large-scale generation of waste tyres. Due to their non-biodegradable nature, waste tyres pose serious environmental challenges when disposed of improperly. Conventional disposal methods such as open burning and landfilling contribute to severe air, soil, and water pollution, along with associated health hazards [1], [8]. Therefore,



the effective management and utilization of waste tyres have become critical concerns in modern engineering and environmental sustainability.

In recent years, the use of waste rubber in road construction has emerged as a promising and sustainable solution. Waste tyres can be processed into crumb rubber and incorporated into bituminous mixes to produce Crumb Rubber Modified Bitumen (CRMB). This modification enhances the physical and mechanical properties of conventional bitumen, including improved elasticity, flexibility, and resistance to deformation [2], [3]. As a result, rubberized pavements demonstrate better performance under heavy traffic loads and varying climatic conditions.

The incorporation of crumb rubber not only improves pavement quality but also contributes to environmental conservation by reducing the accumulation of non-biodegradable waste. Studies have shown that rubberized roads exhibit increased durability, reduced cracking, enhanced rutting resistance, improved skid resistance, and lower noise levels compared to conventional pavements [6], [10]. Although the initial construction cost may be slightly higher, the long-term benefits, such as reduced maintenance requirements and extended service life, make it an economically viable alternative.

Previous research indicates that the addition of crumb rubber increases the viscosity and softening point of bitumen while reducing penetration value, thereby enhancing its stiffness and durability [3], [6]. Among the various methods of incorporation, the wet process has been found to provide better interaction between rubber and bitumen, leading to improved performance, whereas the dry process is more economical and easier to implement [4], [7]. Experimental studies suggest that an optimum crumb rubber content of approximately 8–12% by weight of bitumen yields the best results [2], [6]. Both laboratory and field investigations confirm that rubberized pavements perform effectively under extreme environmental conditions [1], [9]. Despite these advantages, certain challenges such as higher initial costs, requirement of specialized equipment, and lack of standardized guidelines still exist [4], [5]. Hence, further research and large-scale implementation are necessary to fully realize the potential of this technology.

This study aims to evaluate the feasibility and effectiveness of utilizing waste rubber in road construction by analyzing material properties, incorporation methods, and pavement performance. It also seeks to assess the environmental and economic benefits while identifying the practical challenges associated with the implementation of rubberized bitumen technology.

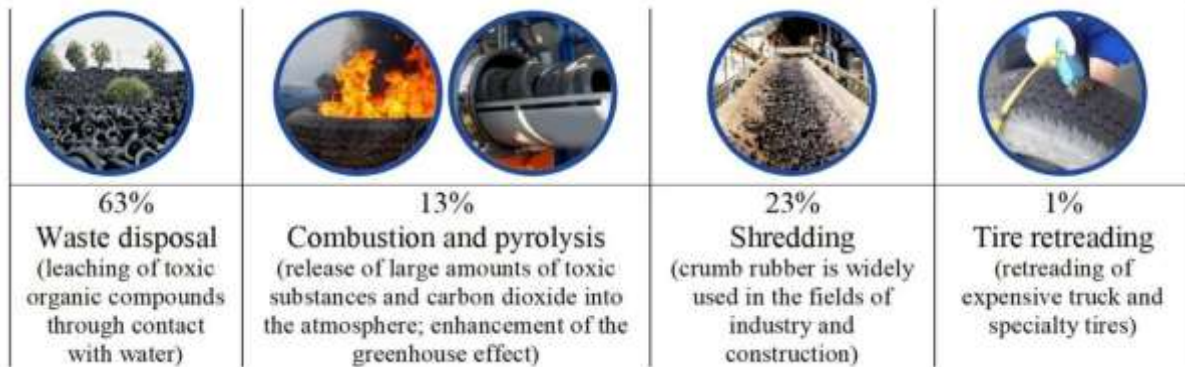


Fig.1. Percentage distribution of various waste rubber management methods – waste Disposal (63%) Combustion and Pyrolysis (13%), Shredding (23%), and Tyre retarding (1%).

2. Materials and Methodology

2.1 Materials Used

The performance of rubberized pavements largely depends on the quality and properties of the constituent materials. The materials used in this study are as follows:

2.1.1 Bitumen

Bitumen is a black, viscous, and adhesive material obtained from petroleum refining, commonly used as a binder in flexible pavements. In this study, conventional paving grade bitumen (VG-30) was selected due to its suitable viscosity and performance under varying temperature conditions.

2.1.2 Crumb Rubber

Crumb rubber is produced by processing waste tyres into small particles, typically ranging from 0.5 mm to 2 mm. It serves as the primary modifying agent in this study, enhancing the elasticity, flexibility, and deformation resistance of bituminous mixes. The crumb rubber was obtained from discarded automobile tyres collected from service stations and waste disposal sites.

2.1.3 Aggregates

Aggregates constitute the major portion of the pavement structure, providing strength and stability. Both coarse aggregates (retained on a 4.75 mm sieve) and fine aggregates (passing through a 4.75 mm sieve) were used. The aggregates were clean, hard, durable, and free from dust and organic impurities.



2.1.4 Mineral Filler

Mineral fillers such as stone dust or cement were used to fill voids in the mix and improve the binding characteristics of the bituminous mixture.

2.2 Collection and Processing of Waste Rubber

The preparation of crumb rubber from waste tyres involved the following steps:

- **Collection:** Waste tyres were collected from local garages, tyre shops, and disposal sites.
- **Cleaning:** The tyres were cleaned to remove dirt, steel wires, and textile fibers.
- **Shredding:** The tyres were cut into smaller pieces (10–50 mm) using shredding machines.
- **Grinding:** The shredded pieces were further processed into fine crumb rubber (0.5–2 mm).
- **Devulcanization (Optional):** Chemical treatment was applied to break sulphur bonds, enhancing compatibility with bitumen.

3. Methodology:

3.1. Wet Process

The wet process is considered the most effective method for incorporating crumb rubber into bitumen [11], [12]. Bitumen was heated to a temperature of 170–180°C, after which crumb rubber (5–15% by weight of bitumen) was gradually added. The mixture was continuously stirred using a mechanical mixer for 45–60 minutes to ensure uniform blending. During this process, the rubber particles absorbed the lighter fractions of bitumen and swelled, resulting in the formation of a gel-like structure. The final product, known as Crumb Rubber Modified Bitumen (CRMB), was subsequently used for pavement preparation. The wet process offers several advantages, including improved interaction between rubber and bitumen, enhanced elasticity and flexibility, and increased resistance to rutting and cracking [11], [13].

3.2. Dry Process

In the dry process, crumb rubber is directly mixed with aggregates instead of bitumen [12], [14]. Initially, the aggregates were heated to a temperature of 160–170°C. Crumb rubber, constituting 1–3% by weight of aggregates, was then added and mixed thoroughly to ensure uniform distribution. Subsequently, hot bitumen was introduced into the mixture to produce the final bituminous mix, which was used for pavement construction. This method is relatively simpler and more economical, and it offers ease of implementation under field conditions [14].



3.3. Hybrid Process

The hybrid process combines both wet and dry techniques to achieve balanced performance in rubberized pavements [13]. In this method, a portion of crumb rubber is blended with bitumen using the wet process, while the remaining portion is mixed with aggregates through the dry process. This approach effectively integrates the advantages of both methods, resulting in improved interaction between materials as well as better workability. Consequently, the hybrid process enhances the overall performance of the pavement by improving its strength, durability, and resistance to deformation [13], [15].

Table 1 :Summary of Experimental Tests

Test Name	Purpose
Hardness Test	Measures resistance to deformation
Compression Set Test	Evaluates elasticity and recovery properties
Adhesion Test	Determines bonding strength with aggregates
Effect of Liquids Test	Assesses resistance to water/chemicals

4. Experimental Methodology

To evaluate the performance and suitability of Crumb Rubber Modified Bitumen (CRMB) for road construction, a series of laboratory tests were conducted. These tests were aimed at determining the physical, mechanical, and durability characteristics of the modified material [16], [17].

4.1 Hardness Test (IRHD)

The hardness test was conducted to determine the resistance of rubber to indentation, which indicates its stiffness and strength [16]. The test was performed using an International Rubber Hardness Tester (IRHD) on a flat rubber specimen. Initially, the specimen was placed on the testing platform, and a minor load was applied to ensure proper contact between the indenter and the specimen. Subsequently, a major load was applied for a duration of 30 seconds. The depth of indentation was measured and converted into a hardness value on the IRHD scale ranging from 0 to 100. The results indicate that higher hardness values correspond to stiffer materials, whereas lower values represent softer materials. An optimum hardness value is desirable to achieve a proper balance between flexibility and strength [16].



4.2 Compression Set Test

The compression set test was carried out to evaluate the ability of rubber to recover its original shape after being subjected to compressive forces [17]. The test involved a compression device, an oven maintained at 70°C, and a thickness measuring gauge. Initially, the original thickness of the specimen (t_0) was measured. The specimen was then compressed to 25% of its original thickness and placed in the oven at 70°C for 22 hours. After removal, the specimen was allowed to cool for 30 minutes, and the final thickness (t_1) was measured.

The compression set was calculated using standard expressions. Lower compression set values indicate better elasticity and recovery properties, while higher values suggest permanent deformation of the material [17].

4.3 Effect of Liquids Test

The effect of liquids test was conducted to evaluate the resistance of rubber to various liquids such as water, oil, and fuel, simulating real environmental conditions [18]. The apparatus included a weighing balance, containers with test liquids, and an oven (if required). The initial weight, volume, and hardness of the specimen were recorded before immersion. The specimen was then immersed in the selected liquid and maintained at room temperature or 70°C for a period of 24–72 hours. After immersion, the specimen was removed, dried, and its final weight and dimensions were measured. An increase in weight indicates absorption of liquid, while a decrease in hardness suggests material degradation. Good-quality rubber is expected to show minimal changes in these properties [18].

4.4 Adhesion Test

The adhesion test was performed to determine the bonding strength between crumb rubber and bitumen [19]. A tensile testing machine was used for this purpose. A rubber-bitumen specimen was prepared and fixed in the machine. Tensile force was gradually applied until failure occurred, and the maximum force required to break the bond was recorded. Higher force values indicate strong adhesion between rubber and bitumen, whereas lower values suggest weak bonding [19].

4.5 Significance of Experimental Tests

The conducted experimental tests are essential for evaluating the durability, strength, and performance of crumb rubber modified bitumen. These tests help in assessing the behavior of the material under real environmental and loading conditions, determining its suitability for



road construction, and comparing its performance with that of conventional bitumen [16], [20].

5. Results and Discussion

The experimental investigation on Crumb Rubber Modified Bitumen (CRMB) indicates a significant improvement in the physical and mechanical properties of conventional bitumen. The incorporation of crumb rubber enhances the overall performance and durability of flexible pavements.

The results of the hardness test show that the addition of crumb rubber increases the stiffness of the binder while maintaining adequate flexibility. Similarly, compression set test results indicate improved elastic recovery, which helps in reducing permanent deformation in pavements. The modified binder also exhibits enhanced resistance to rutting and cracking due to its increased viscosity and softening point. Improved elasticity enables the material to effectively absorb traffic-induced stresses, thereby minimizing crack formation.

Furthermore, the adhesion test confirms strong bonding between rubber and bitumen, which improves pavement durability by reducing stripping of aggregates and increasing resistance to moisture damage. The effect of liquids test demonstrates that CRMB has good resistance to water, oil, and other chemicals. Minimal variations in weight and hardness indicate high durability under adverse environmental conditions.

Compared to conventional bitumen, CRMB offers several advantages, including an increase in pavement life by approximately 25–40%, reduced maintenance frequency, improved skid resistance and road safety, and better performance under extreme temperature conditions. Although the initial construction cost is slightly higher, reduced maintenance requirements and extended service life make CRMB an economically viable option. Additionally, the utilization of waste tyres contributes to environmental protection and supports sustainable infrastructure development. The application of CRMB in road construction has been successfully demonstrated in various regions, highlighting its effectiveness under real field conditions.

Case Studies in India

Tamil Nadu:



Tamil Nadu has extensively adopted rubberized roads, which have shown excellent performance under heavy traffic. The pavements exhibit reduced cracking, improved surface quality, and lower maintenance requirements.

Kerala:

In high rainfall regions of Kerala, rubberized roads have demonstrated superior resistance to water damage and pothole formation. Enhanced flexibility helps maintain pavement integrity under extreme weather conditions.

Maharashtra:

Pilot projects in Maharashtra, including stretches near the Mumbai–Pune Expressway, indicate improved durability and longer service life. These roads show fewer surface defects and reduced repair frequency.

International Case Studies

United States:

Rubberized asphalt has been in use since the 1960s, particularly in states like California and Arizona. These pavements have shown increased lifespan, reduced noise levels, and improved skid resistance.

Australia:

Rubberized roads in Australia have been used to reduce urban noise pollution. Studies indicate enhanced driving comfort and durability compared to conventional pavements. The case studies reveal that the use of crumb rubber modified bitumen (CRMB) leads to a significant increase in pavement life by approximately 25–40%, along with a noticeable reduction in cracks and potholes. The pavements demonstrate improved performance under heavy traffic conditions and exhibit better resistance to water and temperature variations. Additionally, rubberized roads require lower maintenance over their life cycle. These findings confirm that rubberized bitumen technology is both feasible and beneficial, and its successful implementation across diverse regions supports its large-scale adoption for sustainable infrastructure development.

6. Conclusion

The utilization of waste rubber in road construction offers an effective solution to both environmental and infrastructural challenges. The incorporation of crumb rubber into bitumen significantly improves pavement properties, including flexibility, durability, and resistance to rutting and cracking. The study demonstrates that CRMB performs better than conventional



bitumen under heavy traffic loads and varying climatic conditions. Experimental results confirm enhanced elasticity, strong adhesion, and improved resistance to deformation and environmental effects.

Although the initial construction cost is slightly higher, long-term benefits such as reduced maintenance, extended service life, and improved performance make it an economically viable option. Furthermore, the use of waste tyres reduces landfill accumulation and environmental pollution.

Therefore, the adoption of rubberized bitumen technology is strongly recommended for sustainable road construction. With proper standardization, implementation, and awareness, it has significant potential to contribute to durable, cost-effective, and eco-friendly infrastructure development.

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