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Performance Evaluation of Crumb Rubber Modified Bitumen for Sustainable Flexible Pavement Construction

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ABSTRACT

The rapid increase in vehicular traffic and the growing demand for durable road infrastructure have necessitated the development of improved pavement materials. At the same time, the disposal of waste tyres has emerged as a significant environmental concern due to their non-biodegradable nature. This study focuses on the performance evaluation of crumb rubber modified bitumen (CRMB) as a sustainable alternative to conventional bitumen for flexible pavements. In this research, crumb rubber obtained from waste tyres was incorporated into bitumen in varying proportions (4%, 6%, 8%, 10%, and 12% by weight of bitumen). Laboratory tests were conducted to evaluate the physical and mechanical properties of both conventional and modified binders. These tests included penetration, ductility, softening point, and specific gravity tests. Additionally, Marshall Stability and flow tests were performed to assess the performance characteristics of bituminous mixes prepared using CRMB. The experimental results indicate that the addition of crumb rubber significantly influences the properties of bitumen. An increase in softening point and viscosity was observed, indicating improved resistance to high-temperature deformation. Conversely, penetration and ductility values decreased, suggesting increased stiffness of the modified binder. Marshall Stability values showed an increasing trend up to optimum crumb rubber content, demonstrating enhanced strength and load-bearing capacity of the mix. The study concludes that CRMB improves the durability, stability, and performance of flexible pavements while also providing an effective solution for waste tyre management. Therefore, the use of crumb rubber in bitumen is both an environmentally sustainable and economically viable approach for modern road construction.

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

1. Introduction

The rapid growth in vehicular traffic and urbanization has led to a significant increase in the generation of waste tyres, posing serious environmental and disposal challenges worldwide. Waste tyres are non-biodegradable and occupy large landfill spaces, leading to environmental degradation, air pollution, and health hazards. Improper disposal methods such as open burning release toxic gases, including carbon monoxide, hydrocarbons, and particulate matter, which adversely affect both human health and ecological balance. Therefore, sustainable and eco-friendly solutions for managing waste tyres have become a critical area of research [1].

One of the most effective approaches for utilizing waste tyres is their incorporation into road construction materials. The use of crumb rubber derived from discarded tyres in bituminous mixes has gained considerable attention due to its environmental and engineering benefits. Crumb rubber is produced by shredding and processing waste tyres into small particles, which are then blended with bitumen to improve pavement performance. This approach not only reduces the burden on landfills but also enhances the properties of conventional bitumen [2].

Flexible pavements constructed using conventional bitumen often suffer from distresses such as rutting, cracking, and fatigue failure due to increasing traffic loads and varying climatic conditions. The modification of bitumen with crumb rubber improves its rheological and mechanical properties, thereby enhancing the durability and service life of pavements. Rubberized bitumen exhibits improved elasticity, resistance to deformation, and better performance under temperature variations compared to conventional binders [3], [4].

In India, the application of crumb rubber modified bitumen (CRMB) has been widely adopted in road construction. A significant length of road networks has been developed using rubberized asphalt, contributing to improved pavement performance and sustainability. The use of CRMB not only minimizes environmental pollution caused by waste tyres but also reduces the consumption of natural resources, making it a cost-effective and sustainable solution for infrastructure development [5], [6].

Despite its advantages, the incorporation of crumb rubber in bitumen requires careful evaluation of its performance characteristics. Factors such as optimal rubber content, mixing temperature, and compatibility with base bitumen play a crucial role in determining the effectiveness of CRMB. Therefore, it is essential to study and evaluate the performance of crumb rubber modified bitumen to ensure its suitability for long-term pavement applications.

2. Materials and Methods

In the ongoing appraisal the outright Degree took on was Thick Evaluated Bituminous Macadam and Base Course blend arranging tests on totals and bituminous covers are driven in the lab to outline their properties and to genuinely research their respectability to be utilized as street improvement materials.

Fundamental Constituents of a Blend

Aggregate

Coarse Aggregate: Offer compressive and shear strength and shows unprecedented interlocking properties.

Material held tight 2.36 mm IS sifter is taken as coarse totals.

Fine totals: Makes up for the deficiencies in the coarse total and hardened of bitumen.

Material passing 2.36 mm IS sifter and held tight 0.075 mm or 75 microns IS sifter is taken as Fine totals.

Mineral Filler: Makes up for the lack between the fine totals, solidifies the bitumen and offers porousness. Concrete was utilized as mineral filler in the ongoing overview.

Fastener: The sort of lock acknowledges a major part in the presentation of Thick Reviewed Bituminous Macadam Blend. In the ongoing review, the impact of these two kinds of folios on Thick Evaluated Bituminous Macadam Blend has been investigated. The Binder material utilized is Scrap Elastic altered Bitumen.

Research Testing of Materials

All out In the ongoing review, the Rock stone chips are utilized. Smasher run Stone development is utilized as Filler. Customary Portland concrete is utilized as Mineral Filler.

Filler:

Filler could begin from fines in the total or be consolidated the sort of concrete, lime, or ground rock. Filler essentially impacts the voids content and the robustness of the bitumen-fines framework. The particular gravity of filler should be considered. The filler material utilized in the review is concrete. The filler will be liberated from typical poisons and have a versatility record of under 4%.

Bitumen:

The positive properties of bitumen rely on the blend type and improvement. If all else fails, bitumen should bunch following positive properties.

The bitumen ought not to be exceptionally temperature helpless, i.e., during the most sizzling climate the blend shouldn't turn out to be excessively delicate or unsteady, besides during cold climate.

The consistency of the bitumen at the hour of mixing and compaction should please. This can be achieved by the utilization of lessens or emulsions of sensible grades or by warming the bitumen and aggregates going before mixing.

There ought to be OK love and hold between the bitumen and totals utilized in the blend.

3. Results and Discussion

Penetration Tests were done on standard bitumen and changed the bitumen with 4%, 6%, 8%, 10%, and 12% of the elastic waste substance. The outcome was displayed in Table 4.2. From the possible result of the test, the section an infiltration force for standard bitumen was 46 mm. This worth respect diminished with the drawn-out extent of the crumb elastic waste added.

Higher Penetration regards making the harder degree of dark top, giving additional fortitude to the road, and reducing water hurts.

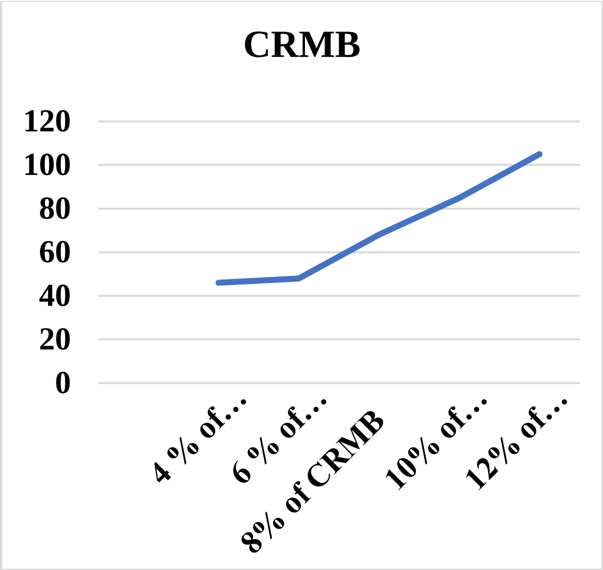

Figure 1: Relation b/w Penetration Vs CRMB

The softening point of the given bitumen model is the average of the two steel balls' characteristics for the nearest 0.5°C. In the range of CRMB bitumen temperatures between 40-60ºC, Increase should not perform better than C. For the range between 61-80*C, Increase could perform better than 1.5°C.

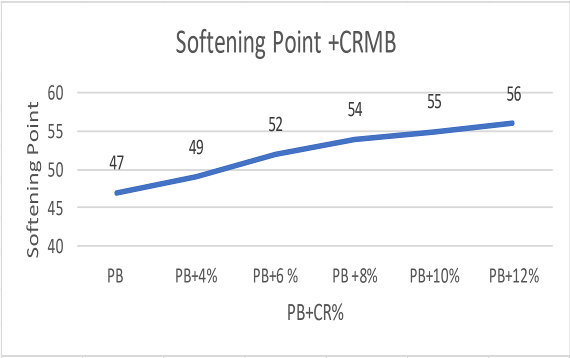

Figure 2: Softening Point-Plane and CRMB

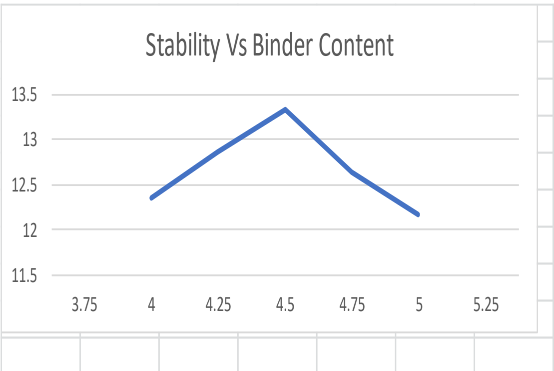

Figure 3: Stability vs Binder Content (DBM GRADE)

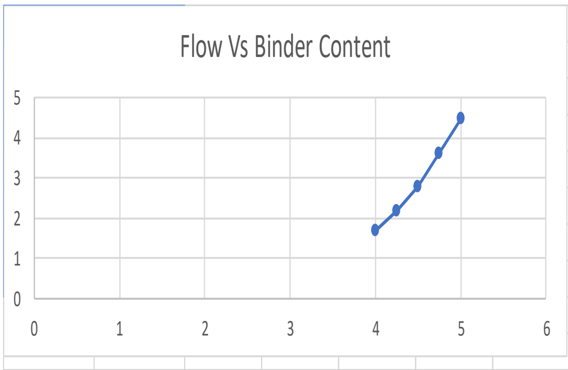

Figure 4: Flow and Binder Content (DBM GRADE)

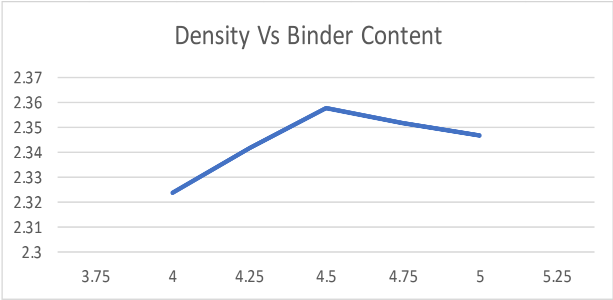

Figure 5: Density and Binder Content (DBM GRADE)

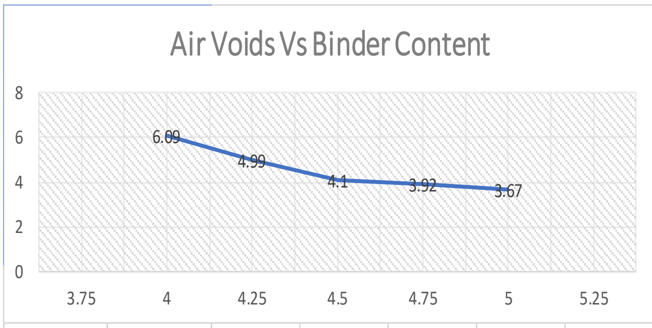

Figure 6: Air Voids and Binder Content (DBM GRADE)

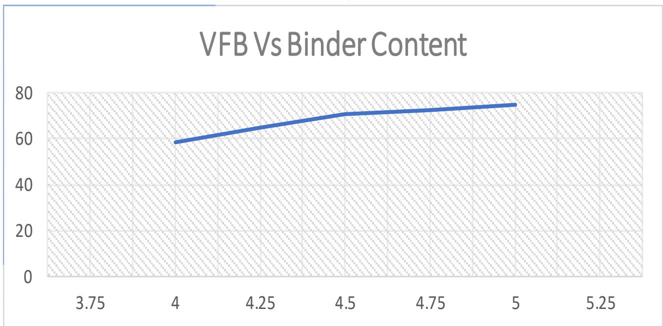

Figure 7: VFB vs Binder Content (DBM GRADE)

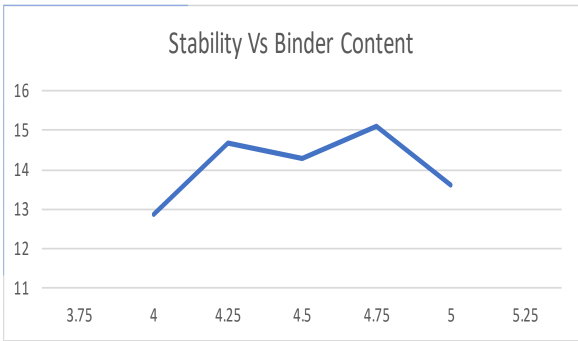

Figure 8: Stability Vs Binder Content (HOT MIX)

Flow Vs Binder Content

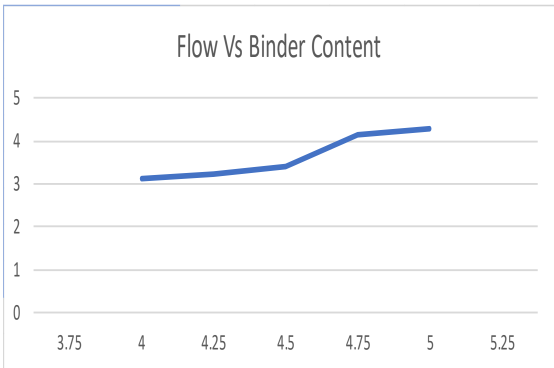

Figure 9: Flow Vs Binder Content (HOT MIX)

Density Vs Binder Content

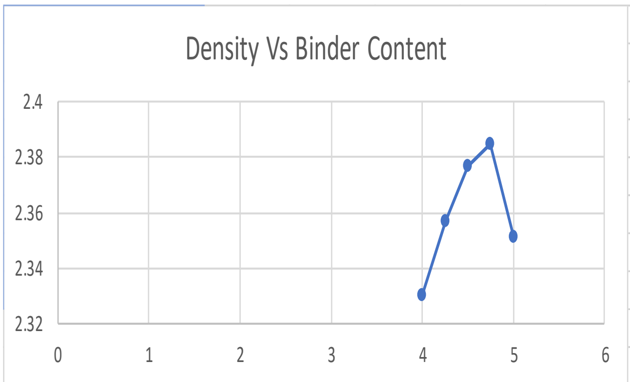

Figure 10: Density Vs Binder Content (HOT MIX)

Air Voids Vs Binder Content

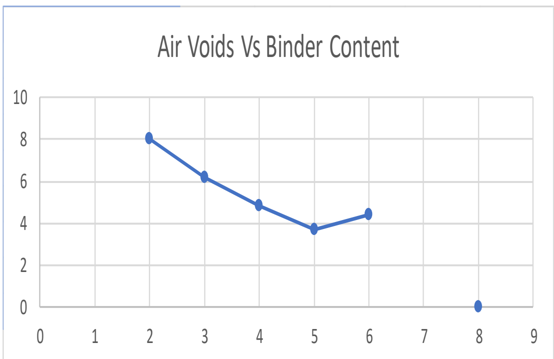

Figure 11: Air Voids Vs Binder Content (HOT MIX)

VFB Vs Binder Content

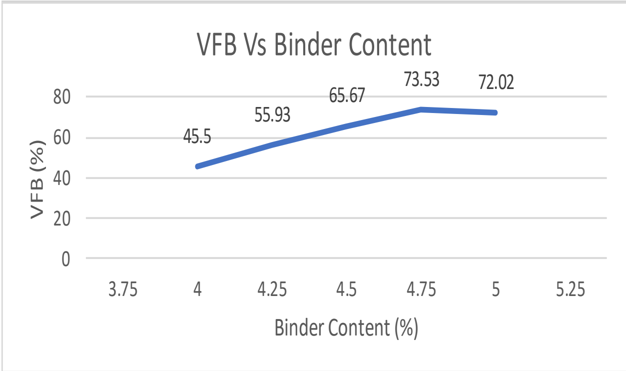

Figure 12: VFB vs Binder Content (HOT MIX)

4. Conclusion

Based on the experimental investigation carried out for the performance evaluation of crumb rubber modified bitumen, the following conclusions are drawn:

- The incorporation of crumb rubber in bitumen leads to a significant improvement in the mechanical properties of flexible pavements, particularly in terms of stability and strength.
- The softening point increases with the addition of crumb rubber, indicating enhanced resistance to high temperatures and reduced susceptibility to rutting.
- A decrease in penetration and ductility values was observed with increasing crumb rubber content, reflecting increased stiffness and improved resistance to deformation.
- Marshall Stability results indicate that CRMB mixes exhibit higher stability values compared to conventional mixes, confirming their superior load-bearing capacity.
- An optimum crumb rubber content exists (generally around 6%–8%), at which the bituminous mix shows the best overall performance in terms of strength and durability.
- The addition of crumb rubber improves the binding characteristics between aggregates and bitumen, resulting in better cohesion and reduced stripping.
- CRMB mixes show reduced air voids and moisture susceptibility, thereby enhancing resistance to water damage and oxidation.

- The use of crumb rubber contributes to noise reduction and improved riding quality due to its elastic properties.
- Utilization of waste tyres in pavement construction provides an effective method for solid waste management, reducing environmental pollution and landfill burden.
- The modified bitumen exhibits better performance under heavy traffic conditions, making it suitable for highways and high-load pavements.
- From an economic perspective, CRMB is a cost-effective alternative due to reduced maintenance requirements and extended pavement life.
- Overall, crumb rubber modified bitumen proves to be a sustainable, durable, and high-performance material for flexible pavement construction, aligning with modern environmental and engineering requirements.

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