

Performance Evaluation and Particulate Leachate Assessment of Crumb Rubber Modified Bitumen-Modified Porous Asphalt Pavements

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Abstract:

Waste tyres create a persistent disposal challenge, while porous asphalt pavement provides interconnected air voids that allow water to pass through the pavement structure. Processing waste-tyre rubber into crumb rubber and incorporating it into bitumen offers a potential reuse route in road construction. This case-study paper presents the objectives, research background and proposed methodology for evaluating porous asphalt prepared with Crumb Rubber Modified Bitumen (CRMB). The assessment combines binder characterization, engineering performance tests on porous asphalt specimens, and controlled water-exposure assessment of collected leachate. The proposed tests include penetration, softening point, ductility and viscosity of the binder, as applicable; density, air-void content, stability, Cantabro abrasion loss, strength and permeability of the mixture; and assessment of possible tyre-derived particles and selected chemical constituents in leachate. The study is intended to consider pavement performance and environmental behaviour together. The exact binder grade, crumb-rubber content, particle-size range, mixing parameters and analytical methods are to be selected according to the approved project design, relevant standards and available laboratory facilities.

Keywords: - crumb rubber modified bitumen, porous asphalt, waste tyre rubber, pavement performance, Cantabro loss, permeability, leachate, tyre-derived particles, environmental assessment.

I. INTRODUCTION

Increasing vehicle use generates large quantities of waste tyres that are difficult to dispose of safely. One potential reuse method is to process tyre rubber into crumb rubber and incorporate it into bitumen for road construction. The modified binder is commonly referred to as Crumb Rubber Modified Bitumen (CRMB). Rubber modification can alter binder viscosity, elasticity and resistance to deformation; the final behaviour depends on the rubber characteristics, binder grade, rubber content and processing conditions.

Porous asphalt is an open-graded pavement mixture containing interconnected air voids that allow water to pass through the pavement. This structure can improve surface drainage during rainfall, but it can also

make the mixture more vulnerable to aggregate loss (ravelling) and moisture-related deterioration if the binder and mixture are not appropriately designed.

The movement of water through porous asphalt also raises an environmental question. Water in contact with rubber-modified pavement may carry tyre-derived particles or selected chemical constituents. Their presence and identity should be established through suitable testing rather than assumed. Therefore, the project considers two connected aspects: engineering performance of CRMB porous asphalt and the possible release of tyre-derived material during controlled water exposure.

II. OBJECTIVE

1. To study the basic properties of Crumb Rubber Modified Bitumen.
2. To examine the suitability of CRMB for use in porous asphalt pavement.
3. To prepare porous asphalt mixtures using CRMB according to the approved mix design.
4. To evaluate the engineering performance of the mixture through suitable laboratory tests.
5. To assess density, air-void content, stability, abrasion loss, strength and permeability, as applicable to the selected design.
6. To investigate the possibility of tyre-derived particle or selected chemical release during controlled water exposure.
7. To consider pavement performance and potential environmental implications together.

III. LITERATURE REVIEW

The literature reviewed in the CRMB project report covers crumb rubber modified binders, porous asphalt mixture performance and environmental leaching from pavement materials. Studies on crumb-rubber modification discuss changes in viscosity, elasticity, stiffness and resistance to permanent deformation. They also indicate that performance depends on rubber content and particle size, binder grade, temperature and mixing duration.

Research on porous asphalt describes the drainage benefits provided by interconnected air voids and the need to maintain sufficient binder cohesion. Common performance considerations include stability, air-void content, permeability, abrasion or Cantabro loss, moisture resistance and durability. The open structure is useful for drainage, but aggregate loss and moisture damage remain important design considerations.

The report also reviews research on leaching from asphalt and recycled-material pavements. Water exposure may mobilize selected chemical constituents or small particles, so environmental assessment requires suitable sampling, controls and analytical methods. The report identifies a need to consider engineering performance and potential environmental release together, rather than treating them as entirely separate questions.

- Ren, Liu, Xu and Lin (2021): investigated crumb-rubber/styrene-butadiene-styrene modified porous asphalt binder and mixture, including the influence of rubber swelling and degradation on binder and mixture performance.
- Shahbazi et al. (2025): reviewed rubber- and plastic-waste-modified asphalt binders and mixtures with attention to performance under environmentally induced distress.
- Akıllı El, Yılmaz and Yalçın (2026): studied the effect of crumb-rubber-modified binders on mechanical properties of semi-rigid pavements prepared with porous asphalt mixtures.

- The CRMB source report also identifies research on porous pavement drainage, asphalt leaching and environmental behaviour of recycled materials. Full bibliographic details should be checked against the original publications before formal submission.

Research Gap: The reviewed work indicates substantial research on asphalt engineering performance and separate work on leaching from pavement materials. The project focuses on connecting these aspects by evaluating selected engineering properties of CRMB porous asphalt alongside possible tyre-derived particle or chemical release during controlled water exposure. Particle identity and environmental implications require evidence from the selected analytical methods.

IV. METHODOLOGY

The proposed methodology evaluates the binder, porous asphalt mixture and collected leachate in a sequence of material characterization, specimen preparation, performance testing and environmental assessment. The specific mix proportions and test conditions are to be confirmed against the approved project design and applicable test standards.

Proposed Procedure of CRMB Porous Asphalt Evaluation

Selection and verification of bitumen, crumb rubber and aggregates
↓
Characterization of raw materials
↓
Preparation of CRMB using approved proportions and mixing conditions
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Binder characterization: penetration, softening point, ductility and viscosity, as applicable
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Porous asphalt mix design and specimen preparation
↓
Engineering tests: density, air voids, stability, Cantabro loss, strength and permeability
↓
Controlled water exposure and leachate collection
↓
Assessment of tyre-derived particles and selected chemical constituents
↓
Comparison and interpretation of engineering and environmental findings

3.1 Materials and Equipment

- Bitumen: paving bitumen of a grade selected and approved for the project.
- Crumb rubber: processed rubber obtained from waste tyres; particle-size range and proportion are to be fixed in the approved test matrix.
- Aggregates: coarse and fine aggregates suitable for the selected porous asphalt gradation, with filler if required by the mix design.
- Binder preparation equipment: heating arrangement, weighing balance, temperature monitoring and mechanical mixing equipment suitable for the approved CRMB preparation procedure.

- Binder test equipment: penetration apparatus, softening-point apparatus, ductility testing machine and viscosity equipment, as required by the selected tests.
- Mixture test equipment: specimen moulds and compaction equipment, balance, density and air-void measurement facilities, stability testing apparatus, Cantabro loss arrangement and permeability apparatus as required by the test plan.
- Leachate assessment equipment: clean water-exposure containers, collection vessels, filtration or particle-separation equipment and suitable analytical facilities selected for the target particles or chemical constituents.

3.2 Procedure of CRMB Porous Asphalt Evaluation

1. Material selection and verification: Select the bitumen, crumb rubber and aggregates. Record the source and relevant material properties, and confirm the proposed binder grade, rubber content and particle-size range.
2. Raw-material characterization: Determine the required properties of bitumen, aggregates and crumb rubber using the approved test methods. Sieve analysis may be used to verify the crumb-rubber particle-size range.
3. Preparation of CRMB: Heat the bitumen and incorporate the specified crumb rubber using the approved mixing temperature, duration and procedure. Maintain records of material masses and preparation conditions.
4. Binder characterization: Test the prepared binder for penetration, softening point, ductility and viscosity, as applicable. Flash and fire point may be included where required for safe handling and the approved test plan.
5. Porous asphalt mixture design: Select the aggregate gradation and binder content in accordance with the approved mix-design approach. Prepare and compact specimens under controlled conditions.
6. Engineering performance testing: Determine the selected mixture properties, including density, air-void content, stability, Cantabro abrasion loss, strength and permeability. Use the same approved procedures for comparable specimens.
7. Controlled water exposure: Expose selected specimens to a defined volume of water for a controlled duration using clean containers and a documented procedure. Include appropriate blanks or controls where feasible to help distinguish sample-related material from background contamination.
8. Leachate collection and assessment: Collect the water after exposure and assess selected tyre-derived particles or chemical constituents using methods appropriate to the target analytes. Do not classify particles as microplastics solely on the basis of small size; use suitable identification or characterization where available.
9. Comparison and interpretation: Compare the engineering results with the applicable project criteria and examine the leachate findings alongside the material and exposure conditions. State limitations and avoid conclusions beyond the evidence produced by the selected tests.

3.3 Proposed Tests

- Binder tests: penetration, softening point, ductility and viscosity, as applicable to the selected binder and standards.
- Aggregate and crumb-rubber characterization: relevant aggregate properties and gradation; crumb-rubber particle-size verification by sieving where required.
- Porous asphalt tests: density, air-void content, stability, Cantabro abrasion loss, strength and permeability, according to the approved mix design and laboratory facilities.

- Leachate tests: assessment of selected tyre-derived particles and/or chemical constituents in water collected after controlled exposure. The analytical method must be selected to suit the target and should include suitable controls.

3.4 Advantages

1. Reuses a portion of waste tyre rubber in road-construction materials.
2. Assesses both pavement engineering properties and potential environmental behaviour in one study.
3. Porous asphalt can provide pathways for water drainage through interconnected voids.
4. Binder modification may improve selected properties such as elasticity and resistance to permanent deformation, depending on the materials and processing conditions.
5. The test framework can help identify trade-offs between mixture performance and possible release during water exposure.

3.5 Limitations and Considerations

1. CRMB properties depend on binder grade, rubber characteristics, rubber proportion and mixing conditions.
2. Excessive binder viscosity can affect workability, mixing and compaction.
3. Porous asphalt may be susceptible to ravelling or moisture-related deterioration if the mixture is not properly designed.
4. Leachate findings depend on water chemistry, exposure duration, specimen condition, collection procedure and analytical sensitivity.
5. Particle identity cannot be confirmed by appearance or size alone; conclusions must match the capabilities of the characterization method.

3.6 Applications

1. Laboratory evaluation of waste-tyre-rubber-modified binders for pavement materials.
2. Assessment of CRMB use in porous asphalt mixtures intended for drainage-oriented pavement applications.
3. Comparative evaluation of binder and mixture properties under an approved laboratory test programme.
4. Preliminary environmental screening of water exposed to rubber-modified porous asphalt specimens.

3.7 Standards and Test Framework

The source report identifies Indian Standards for paving bitumen and binder tests, including IS 73, IS 1203 for penetration, IS 1205 for softening point, IS 1208 for ductility, IS 1206 (Part 2) for viscosity, IS 17079 for rubber modified bitumen and relevant parts of IS 2386 for aggregates. ASTM D5644-23 is identified for mechanical vibratory sieving of recycled vulcanizate particulate rubber. ISO 21268-1:2019 is mentioned in the source methodology as a possible adapted batch-leaching framework, subject to suitability review and laboratory approval. The current applicable editions, scope and suitability of each standard must be confirmed before testing; the ISO method should not be treated as an asphalt-specific standard without that review.

V. CONCLUSION

The project presents a combined approach to the use of waste tyre rubber in porous asphalt pavement. It considers the engineering properties of Crumb Rubber Modified Bitumen and the resulting porous asphalt mixture, together with the possibility of tyre-derived particle or chemical release during

controlled water exposure. Binder characterization, mixture performance tests and leachate assessment are included because each provides different information needed to evaluate the material. The suitability of CRMB porous asphalt should be interpreted from the measured test results, the selected design parameters and the limitations of the analytical methods. This methodology provides a structured basis for assessing pavement performance and environmental behaviour without assuming outcomes in advance.

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10. ASTM D5644-23. Standard Test Method for Rubber Particles from Recycled Vulcanizate—Particle Size Distribution by Mechanical Vibratory Sieving.
11. ISO 21268-1:2019. Soil quality — Leaching procedures for subsequent chemical and ecotoxicological testing of soil and soil-like materials — Part 1: Batch test using a liquid to solid ratio of 2 l/kg dry matter. Applicability to this project must be assessed before use.