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# Feasibility Analysis, Design and Testing of Crumb Rubber Modified Bitumen for Flexible Pavement

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***Abstract: The increasing demand for sustainable and eco-friendly construction materials has led to significant research in the modification of conventional bitumen used in road construction. This paper investigates the partial replacement of VG-30 grade bitumen with crumb rubber (CR) derived from waste tyres at 6%, 7%, 8%, and 9% by weight. Modified bitumen samples were subjected to Penetration Test (IS 1203), Ductility Test (IS 1208), Softening Point Test (IS 1205), and Marshall Stability Test (ASTM D6927) to assess their physical and mechanical properties. Results demonstrate that increasing CR content decreases penetration (65 mm to 46 mm) and ductility (90 cm to 13 cm), while significantly raising the softening point (45°C to 69°C). Marshall Stability peaked at 8% CR replacement (1.32 kN). The findings confirm that crumb rubber modified bitumen (CRMB) offers improved temperature resistance, enhanced load-bearing capacity, and superior durability, while simultaneously addressing waste tyre disposal challenges. An optimal CR replacement of 8% is recommended for flexible pavement applications in Indian climatic conditions.***
***Keywords: Crumb Rubber Modified Bitumen (CRMB); flexible pavement; penetration test; softening point; Marshall stability; waste tyre recycling; sustainable construction.***

## I. INTRODUCTION

India became the world's third-largest automobile market in December 2022, surpassing Japan, with the automotive sector accounting for approximately 7% of the country's GDP. Tyre production in India rose by 21% in 2022 and a further 6% in 2023, reaching 217.4 million units annually [1]. By weight, 2.5 million metric tons (MT) of tyres have been produced in India each year since 2019.

According to Satish Goyal, President of the Tyre & Rubber Recyclers Association of India (TRRAI), approximately 2 million MT of tyres are discarded as scrap annually after accounting for wear and tear. An additional 0.8 million MT of scrap tyre is imported annually, bringing total tyre waste handled in India to 2.8 million MT. These waste tyres constitute about 1% of total municipal solid waste [2] and pose significant environmental hazards: they are non-biodegradable, serve as breeding grounds for mosquitoes and rodents, release carcinogenic pollutants when burned, and present serious fire risks.

Rubberized asphalt, produced by blending crumb rubber with conventional bitumen, has emerged as a promising solution to this dual challenge of waste management and road quality improvement. The addition of crumb rubber improves skid resistance, reduces noise, increases fatigue resistance, and enhances thermal stability. This paper presents a systematic laboratory investigation into the feasibility of using crumb rubber as a partial bitumen replacement at varying percentages for flexible pavement construction.

### A. *Problem Statement*

The accumulation of waste tyres presents significant environmental challenges including landfill overflow, toxic gas emissions from burning, and resource wastage. Simultaneously, conventional bituminous roads in India suffer premature distress due to high temperatures and heavy traffic loads. This study addresses both issues by evaluating CRMB as a performance-enhancing and environmentally responsible alternative.

### B. *Objectives*

- To study crumb rubber derived from waste tyres and assess its applicability in bituminous roads.
- To evaluate engineering properties (penetration, ductility, softening point, Marshall stability) of CRMB at 6%, 7%, 8%, and 9% replacement levels.
- To compare CRMB properties with conventional VG-30 bitumen and identify the optimum replacement percentage.

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## II. LITERATURE REVIEW

Srivastava et al. [3] evaluated crumb rubber added to 60/70 grade bitumen using the wet process at concentrations of 5–30%. A 10% addition was found optimal, offering improved softening point, stability, and durability while maintaining acceptable ductility. Rubberized bitumen was noted to improve wet-surface traction and reduce noise, with established applications in California, Arizona, Texas, and South Africa.

Kumar and Rajakumara [4] investigated VG-30 bitumen modified with 1–4% crumb rubber. The results showed enhanced specific gravity, softening point, and flash point, while ductility and penetration decreased. Up to 1% CR maintained optimal Marshall Stability and flow; replacement of 5% aggregate with rubber aggregate also produced acceptable results.

Alsheyab et al. [5] conducted a comprehensive review confirming that waste tire rubber addition increases softening point, viscosity, flow, void mineral aggregate (VMA), and Marshall stability, while reducing penetration, ductility, specific gravity, and retained stability. The authors concluded that CR addition is a safe and effective method of managing waste tyres.

Ibrahim et al. [6] reviewed the rheological behavior of CRMB, emphasizing the importance of workable viscosity for construction, and identified rubber particle settling as a key challenge limiting large-scale application. Chemical modifications were proposed to enhance CRMB storage stability.

Zakerzadeh et al. [7] evaluated CR incorporation in Stone Mastic Asphalt (SMA) via wet and dry processes. CR-SMA mixtures demonstrated superior longevity and reduced maintenance, with optimal CR percentages in the 5–15% range. Key challenges include swelling of rubber particles during compaction and high production costs of the wet process.

Mbereyaho et al. [8] partially replaced bitumen with tire rubber waste powder at 5%, 10%, 15%, and 20%. A 5% replacement gave optimal penetration (61.66 tenths mm), softening point (52.75°C), and viscosity, while achieving a 5.3% cost reduction, supporting both sustainability and economic viability.

## III. MATERIALS AND METHODOLOGY

### *A. Materials*

VG-30 grade bitumen was used as the base binder, which is the most commonly adopted grade for flexible pavements in India. Crumb rubber (CR) was obtained from mechanically shredded waste automobile tyres, passing through a 3 mm sieve. Aggregates used in the Marshall Stability test were graded between 12.5 mm and 20 mm (Dense Bituminous Macadam gradation).

### *B. Mix Proportions*

Four replacement levels were investigated: 6%, 7%, 8%, and 9% of the total bitumen weight replaced by crumb rubber. Table I through Table IV summarize the mix proportions for each test.

TABLE I. All Test results

| Test Name | Sample | Bitumen Wt. (g) | CR (%) | New Bitumen Wt. (g) | CR Wt. (g) | Total (g) |
|---|---|---|---|---|---|---|
| Penetration Test | 1 | 50 | 6 | 47.0 | 3.0 | 50 |
| | 2 | 50 | 7 | 46.5 | 3.5 | 50 |
| | 3 | 50 | 8 | 46.0 | 4.0 | 50 |
| | 4 | 50 | 9 | 45.5 | 4.5 | 50 |
| Softening Point Test | 1 | 60 | 6 | 56.4 | 3.6 | 60 |
| | 2 | 60 | 7 | 55.8 | 4.2 | 60 |
| | 3 | 60 | 8 | 55.2 | 4.8 | 60 |
| | 4 | 60 | 9 | 54.6 | 5.4 | 60 |
| Ductility Test | 1 | 85 | 6 | 79.9 | 5.1 | 85 |
| | 2 | 85 | 7 | 79.05 | 5.95 | 85 |
| | 3 | 85 | 8 | 78.2 | 6.8 | 85 |
| | 4 | 85 | 9 | 77.35 | 7.65 | 85 |
| Marshall Stability Test | 1 | 200 | 6 | 188 | 12 | 200 |
| | 2 | 200 | 7 | 186 | 14 | 200 |
| | 3 | 200 | 8 | 184 | 16 | 200 |
| | 4 | 200 | 9 | 182 | 18 | 200 |

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*C. Sample Preparation*

Bitumen was heated to 160–180°C in a laboratory oven. Crumb rubber was gradually added to the molten bitumen and stirred continuously using a mechanical stirrer to achieve uniform dispersion. The mixture was maintained at the specified temperature until a visually homogenous blend was obtained. Prepared samples were allowed to cool to room temperature before testing.

*D. Testing Standards*

- Penetration Test: IS 1203:1978 – standard needle, 100 g load, 5 s duration, 25°C.
- Softening Point Test: IS 1205:1978 – Ring-and-Ball apparatus.
- Ductility Test: IS 1208:1978 – 50 mm/min pull rate at 27°C.
- Marshall Stability Test: ASTM D6927 – 500 g aggregate per sample (passing 20 mm, retained on 12.5 mm sieve).

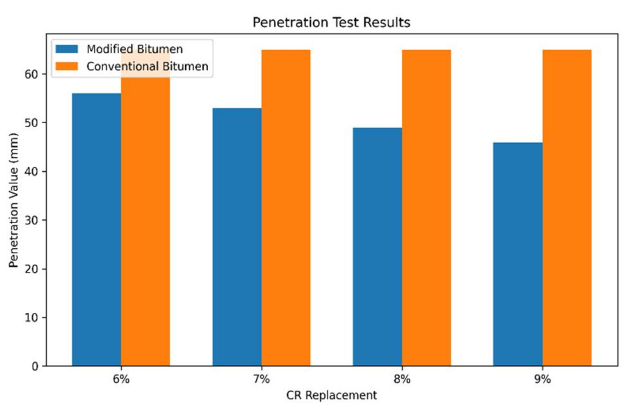
## IV. EXPERIMENTAL RESULTS

*A. Penetration Test*

The penetration test determines the hardness or softness of bitumen. As presented in Table V, penetration values decreased progressively from 65 mm (conventional) to 46 mm at 9% CR replacement, indicating increased stiffness and improved temperature resistance.

TABLE V. Penetration Test Results

| CR Replacement | Penetration (Modified) mm | Conventional (mm) |
|---|---|---|
| 6% | 56 | 65 |
| 7% | 53 | 65 |
| 8% | 49 | 65 |
| 9% | 46 | 65 |




*B. Softening Point Test*

The softening point test indicates the temperature at which bitumen softens under load. Results in Table VI show a consistent increase from 45°C (conventional) to 69°C at 9% CR, confirming significantly enhanced resistance to deformation at elevated temperatures — a critical property for Indian road conditions.

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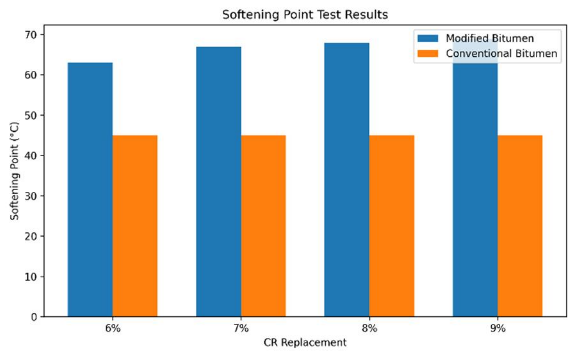
TABLE VI. Softening Point Test Results

| CR Replacement | Softening Pt. (Modified) °C | Conventional (°C) |
|---|---|---|
| 6% | 63 | 45 |
| 7% | 67 | 45 |
| 8% | 68 | 45 |
| 9% | 69 | 45 |

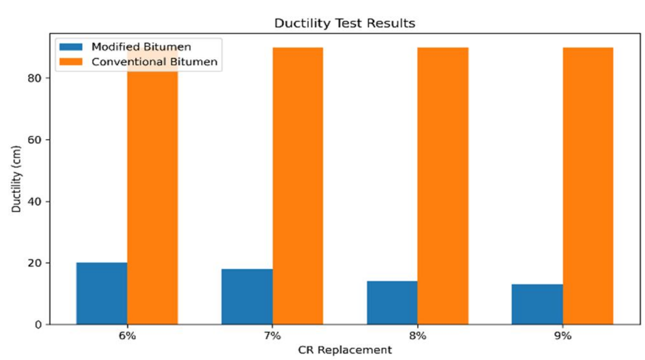



### C. Ductility Test

The ductility test measures the stretching capacity and flexibility of bitumen. As seen in Table VII, ductility decreased sharply from 90 cm (conventional) to 13 cm at 9% CR. This reduction in flexibility is a known characteristic of rubberized bitumen and is acceptable when offset by the gains in hardness and thermal resistance.

TABLE VII. Ductility Test Results

| CR Replacement | Ductility (Modified) cm | Conventional (cm) |
|---|---|---|
| 6% | 20 | 90 |
| 7% | 18 | 90 |
| 8% | 14 | 90 |
| 9% | 13 | 90 |



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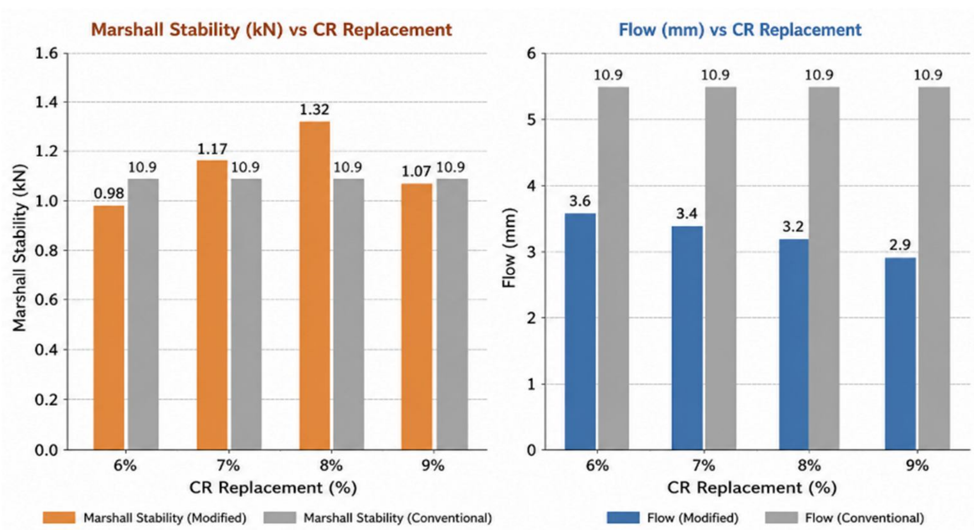
### *D. Marshall Stability Test*

The Marshall Stability test measures the load-bearing capacity and resistance to permanent deformation of a bituminous mix. As shown in Table VIII, stability values increased progressively with CR content, reaching a peak of 1.32 kN at 8% replacement, before declining slightly to 1.07 kN at 9%. Flow values decreased consistently, indicating stiffer mixes at higher rubber content. The 8% CR mix is therefore identified as the optimum blend for maximizing load-bearing performance.

TABLE VIII. Marshall Stability Test Results

| CR Replacement | Marshall Stability (kN) | Flow (mm) | Conventional (kN) |
|---|---|---|---|
| 6% | 0.98 | 3.6 | 10.9 |
| 7% | 1.17 | 3.4 | 10.9 |
| 8% | 1.32 | 3.2 | 10.9 |
| 9% | 1.07 | 2.9 | 10.9 |




## V. DISCUSSION

The experimental results collectively demonstrate that crumb rubber modifies the rheological and mechanical properties of VG-30 bitumen in a consistent and predictable manner. The decrease in penetration values with increasing CR content reflects increased bitumen stiffness, which is beneficial for resisting rutting under heavy traffic loads at high ambient temperatures prevalent in Indian cities.

The progressive increase in softening point — rising by up to 53% over conventional bitumen at 9% CR — is particularly significant. Conventional bitumen with a softening point of 45°C is vulnerable to deformation during Indian summer temperatures which routinely exceed 40°C on road surfaces. CRMB at all tested levels surpasses this threshold considerably.

The reduction in ductility is an inherent trade-off of rubber modification. While values drop sharply compared to conventional bitumen (90 cm), the residual flexibility of 13–20 cm may still be adequate for many pavement applications, particularly in high-temperature zones where excessive ductility is associated with susceptibility to deformation rather than being a performance advantage.

The Marshall Stability results clearly identify 8% CR as the optimum replacement. Beyond this level, the excess rubber particles may interfere with aggregate interlock, causing a reduction in load-bearing capacity. The decreasing flow values indicate that CRMB mixes are progressively more resistant to deformation, which supports the penetration and softening point findings.

From an environmental perspective, the use of crumb rubber from waste tyres as a bitumen modifier addresses the twin problems of tyre waste disposal and premature pavement deterioration. India generates approximately 2.8 million MT of tyre waste annually [1], and diverting even a fraction of this into road construction represents a meaningful contribution to circular economy goals.

## VI. CONCLUSION

This study successfully demonstrated the feasibility of using crumb rubber as a partial replacement for VG-30 bitumen in flexible pavement construction. The following specific conclusions are drawn:

- Penetration values decreased from 65 mm (0% CR) to 46 mm (9% CR), indicating enhanced hardness and improved temperature stability of CRMB.
- Softening point rose from 45°C (conventional) to 69°C (9% CR), confirming markedly improved resistance to high-temperature deformation.
- Ductility decreased from 90 cm (conventional) to 13 cm (9% CR), reflecting reduced flexibility — an acceptable trade-off in high-temperature pavement applications.
- Marshall Stability peaked at 8% CR replacement (1.32 kN), establishing 8% as the optimum rubber content for load-bearing performance.
- CRMB offers a dual benefit: enhanced pavement performance and responsible disposal of hazardous waste tyres, aligning with sustainable construction and circular economy objectives.

Future research should investigate field performance of 8% CRMB trial sections, long-term durability under actual traffic and climatic conditions, replacement levels above 9%, alternative binder types, and life-cycle cost analysis to support policy adoption.

## VII. ACKNOWLEDGMENT

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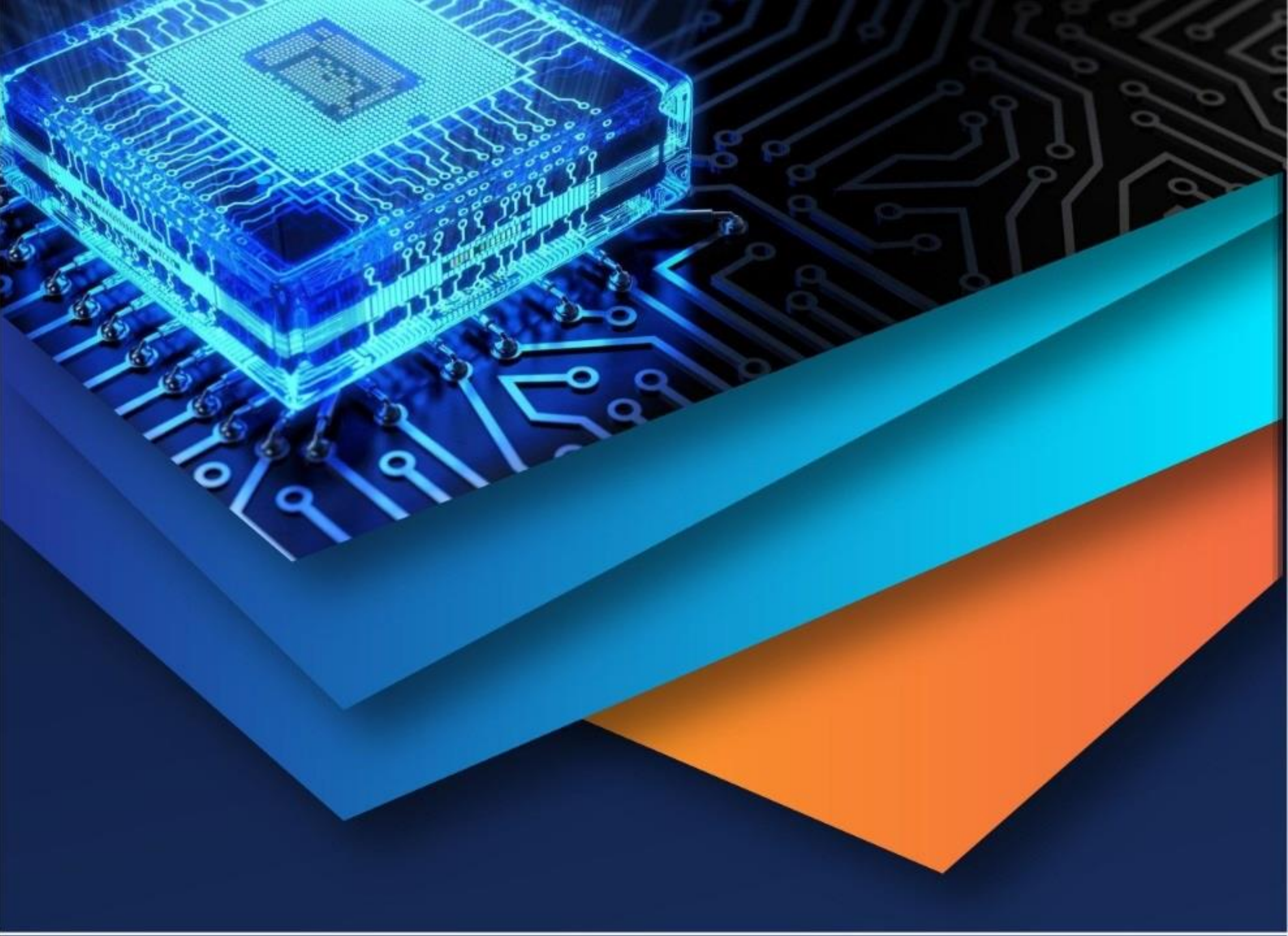


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