SCIENTIFIC CULTURE
www.sci-cult.com

SCIENTIFIC CULTURE, Vol. 12, No. 4, (2026), pp. 5322-5330
Open Access. Online & Print

DOI: 10.5281/zenodo.19455856

EFFECT OF POLYPROPYLENE AS AN ADDITIVE ON CRUMB RUBBER MODIFIED BITUMEN FOR THE CONSTRUCTION OF ROADS

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Received: 09/12/2025
Accepted: 04/02/2026

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ABSTRACT

In recent years, crumb rubber-modified bitumen has gained importance for road construction due to its durability, flexibility, and resistance to harsh climatic conditions. The addition of polypropylene to crumb rubber-modified bitumen enhances road performance, increases longevity, and reduces maintenance costs. In this work, the effect of polypropylene as an additive for crumb rubber-modified bitumen was examined. The Dynamic Shear Rheometer (DSR) test showed a High Complex Modulus and a Low Phase Angle, indicating effective cracking resistance due to the addition of polypropylene. A Bending Beam Rheometer (BBR) test was conducted to evaluate the flexural stiffness and relaxation properties at low temperatures, demonstrating the ability to resist cracking.

KEYWORDS: Polypropylene, Crumb Rubber Modified Bitumen, Crack Prevention, Rutting, Bending Beam Rheometer

1. INTRODUCTION

Polymer-modified crumb rubber (PMCR) has gained prominence in asphalt binder applications due to its ability to improve pavement performance and address the challenge of waste tire disposal. PMCR binders are produced by blending crumb rubber derived from recycled tires with polymers such as styrene-butadiene-styrene (SBS), ethylene-vinyl acetate (EVA), or recycled low-density polyethylene (RLDPE) [1-4]. This formulation enhances resistance to rutting, cracking, and aging, and improves workability and storage stability when compared to conventional rubberized binders or bitumen.

The incorporation of polypropylene (PP) as an additive in crumb rubber modified bitumen (CRMB) has demonstrated significant improvements in asphalt binder performance. Notably, enhancements in rutting resistance, tensile strength, and fatigue life have been observed. Studies report that blends of crumb rubber and polypropylene decrease penetration, raise the softening point, and increase the complex modulus at elevated temperatures [5-8]. These modifications reduce the binder's susceptibility to permanent deformation, making it more suitable for use in heavy traffic conditions and hot climates.

Crumb rubber primarily enhances flexibility and low-temperature performance, whereas polypropylene increases stiffness and stability at high temperatures [9]. The combination of these materials offers comprehensive improvements across diverse service conditions [10]. However, higher polymer content may lead to reduced workability due to increased viscosity and may negatively impact stability.

Crumb rubber typically yields the most substantial improvements among modifiers; however, polypropylene also offers significant advantages, especially when combined with crumb rubber [12-13]. Utilizing both polypropylene and crumb rubber in bitumen modification enhances road durability and contributes to sustainability by repurposing waste materials and minimizing environmental impact [14]. In summary, the addition of polypropylene to CRMB markedly improves the mechanical and rheological properties of bitumen, leading to more durable and resilient road surfaces.

2. METHODOLOGY

2.1. *Collection of crumb rubber samples:*

Crumb rubber samples were collected from the MARN Flexible Rubber Factory in Al-Nahdah Ghala, Muscat, Sultanate of Oman.

2.2. *Penetration grade bitumen*

Penetration grade bitumen 60/70 was purchased from Muscat International Bitumen LLC, Al Qurum, Muscat, Sultanate of Oman.

2.3. *Preparation of polymer mixed crumb rubber bitumen*

Bitumen was preheated to 180°C to reach the required fluidity. Polypropylene was separately heated in a beaker to 200°C. Subsequently, bitumen, polypropylene, and crumb rubber were combined and mixed with a high-shear homogenizer at 180°C for60 minutes at 3500 rpm to ensure homogeneity. After blending, the mixture was cooled to room temperature, stored in airtight containers, and preserved for subsequent testing.

Table 1: The properties of the polypropylene.

Polypropylene	
Shape	Granular (1–3 mm)
Density (g/cm^3)	0.875–0.925
Melting point (◦C)	Less than 180

2.4. *Short-term ageing of PCRMB*

10 grams of PCRMB are poured into RTFOT bottles as per ASTM D2872. The bottles are then placed in the RTFOT at 163°C for 75 minutes, ensuring continuous rotation and airflow [15]. After this period, the samples are removed from the RTFOT and measured for penetration, softening point, viscosity, and DSR.

2.5. *Long-term ageing of PCRMB*

The short-term aged PCRMB samples are subjected to long-term aging. The RTFOT-aged samples are then placed in the PAV, where they are exposed to air at a pressure of 2.1 MPa and a temperature of 100–110°C for 20 hours [16]. After PAV aging, the samples are evaluated for changes in penetration point, softening point, and BBR.

2.6. *Viscosity test*

The viscosity of PCRMB was determined in accordance with ASTM D4402. The binder was heated in an oven to 135 °C until a uniform consistency was achieved. It was then transferred to a preheated rotational viscometer sample chamber at the specified level, ensuring that no air bubbles remained. The chamber was placed in a temperature-controlled bath to reach thermal equilibrium. The appropriate spindle was immersed to the designated depth at 20 rpm, and the test commenced. Once the torque reading stabilized, the viscosity value displayed by the instrument at that temperature was recorded [17].

2.7. Softening point test

The softening point of PCRMB was determined in accordance with ASTM D36 using the Ring-and-Ball apparatus. The binder was heated and poured into two clean brass rings, which were allowed to cool. The surfaces were trimmed to remove excess binder, resulting in smooth, flush discs. The rings were suspended in a water bath, and standard steel balls were placed centrally on each binder disc. The bath temperature increased at a constant rate until each softened disc permitted its ball to drop 25 mm. The bath temperature at the point of ball drop was recorded [18].

2.8. Penetrometer test

The penetration value of PCRMB was determined in accordance with ASTM D5. The binder was heated to a fluid state, poured into standard penetration cups, and allowed to cool. A standard needle with a total load of 100 g was positioned on the binder surface and released to penetrate vertically for 5 seconds. The depth of penetration, measured in 0.1 mm increments, was recorded from the instrument display [19].

2.8. Dynamic Shear Rheometer test

The Anton Paar DSR Smart Pave 92 was used to assess the rheological properties of polypropylene-crumb rubber-modified bitumen (PCRMB) at various temperatures and loading conditions. A temperature-sweep test was performed in controlled-strain mode, with temperatures ranging from 20 to 40 °C and a loading frequency of 10 rad/s, to examine viscoelastic behavior. The primary viscoelastic parameters measured were complex modulus (G^*) and phase angle (δ). For each test, 1.0 g of the sample was placed on the lower plate, and the upper plate was aligned parallel at a 1 mm gap. Excess binder was removed from around the plates prior to stress application.

2.9. Bending Beam Rheometer test

The B216 BBR PLUS assesses the low-temperature flexural creep properties of asphalt binder in compliance with international standards such as ASTM D6648. This instrument functions across a temperature range from ambient conditions to –40 °C, maintaining thermal stability within ±0.03 °C to ensure accurate measurements. Each test involves a 250-second duration, comprising a 240-second loading interval and a subsequent 10-second recovery period.

3. RESULT AND DISCUSSION

Short-term aging, often simulated through the Rolling Thin Film Oven Test (RTFOT), results in significant changes in the physical and rheological properties of both unmodified bitumen and crumb rubber-modified bitumen. The incorporation of crumb rubber typically enhances the aging resistance of bitumen.

3.1. Viscosity

Viscosity serves as a key parameter affecting the performance characteristics of polymer-crumb rubber-modified bitumen. The addition of polypropylene and crumb rubber to bitumen generally leads to a marked increase in viscosity [21]. Viscosities for both aged and unaged samples were determined at 135 °C, as shown in Figure 1. For aged samples, PCRMB exhibited a viscosity of 1.58 Pa·s, while bitumen and CRMB recorded values of 0.78 Pa·s and 1.5 Pa·s, respectively. In unaged samples, viscosities measured 0.65 Pa·s for bitumen, 0.95 Pa·s for CRMB, and 1.1 Pa·s for PCRMB. This increase in viscosity is primarily due to the swelling of rubber particles, which absorb lighter components from the bitumen and produce a stiffer, more elastic binder.

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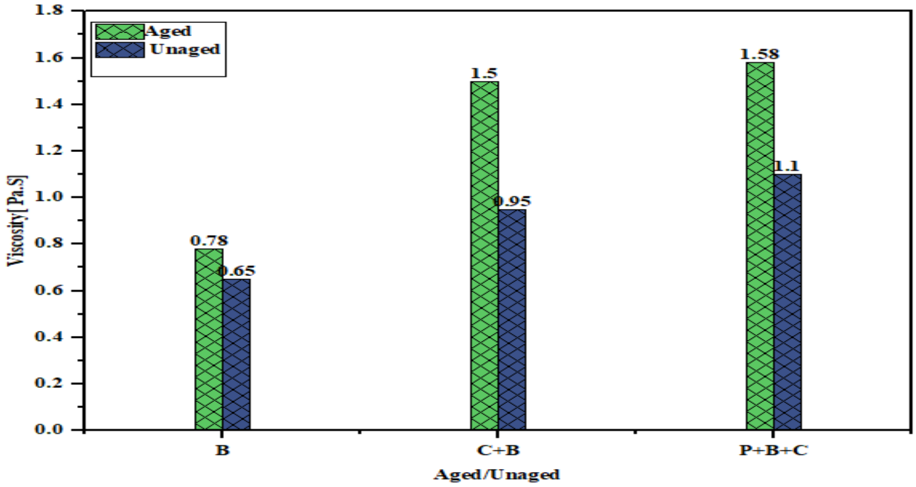

Fig.1: Comparisons of aged and unaged samples-bitumen (B), crumb rubber modified bitumen (C+B), and polymer crumb rubber modified bitumen (P+B+C)

3.2. *Softening Point*

Numerous studies have consistently shown that incorporating crumb rubber into bitumen increases its softening point, thereby enhancing the binder's resistance to deformation at high temperatures and making it more suitable for road construction in hot climates [22]. The softening points of aged bitumen, CRMB, and PCRMB are 52 °C, 68 °C, and 72 °C, respectively. In contrast, unaged samples exhibit slightly lower softening points but maintain an increasing trend, with values of 57 °C, 68 °C, and 72 °C as shown in figure-2. The addition of polypropylene and crumb rubber to bitumen is responsible for this improvement. Notably, after ageing, the change in softening point is less pronounced compared to conventional bitumen, indicating improved stability and enhanced resistance to both thermal and oxidative ageing.

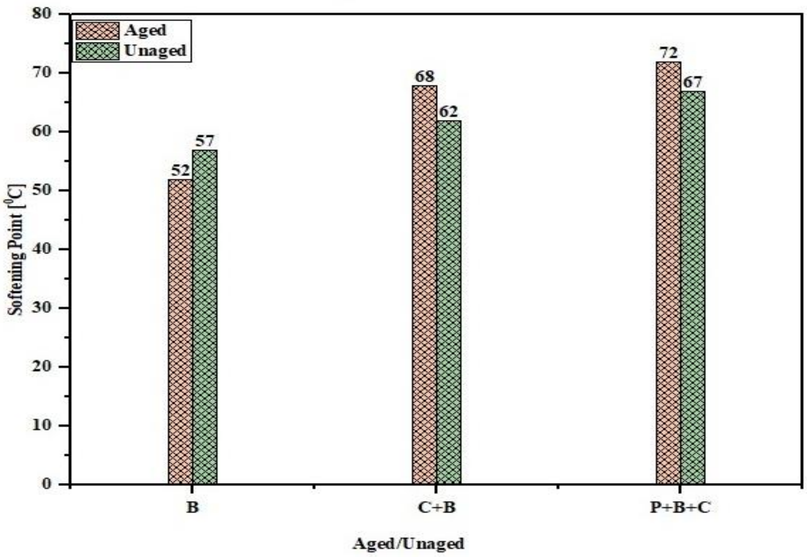

Fig.2: Comparisons of Softening Point aged and unaged samples- bitumen (B), crumb rubber modified bitumen (C+B), and polymer crumb rubber modified bitumen (P+B+C)

3.3. *Penetration valve*

Incorporating polypropylene into crumb rubber-modified bitumen (C+B) significantly reduces the penetration value, indicating a stiffer and more rigid binder. Figure 3 displays the penetration values for aged and unaged samples of bitumen, CRMB, and PCRMB. For aged samples, penetration values are 56 mm for bitumen, 41 mm for CRMB, and 47 mm for PCRMB. In unaged samples, the values are 51 mm for bitumen, 43 mm for CRMB, and 45 mm for PCRMB. The combined use of crumb rubber and polymers increases penetration resistance more effectively than crumb rubber alone. Furthermore, polypropylene-crumb rubber-modified bitumen exhibits enhanced elasticity relative to the reference bitumen.

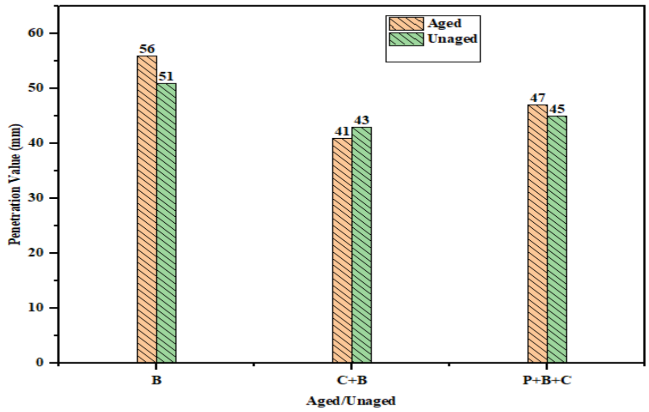

Fig.3: Comparisons of Penetration value of aged and unaged samples- bitumen (B), crumb rubber modified bitumen (C+B), and polymer crumb rubber modified bitumen (P+B+C)

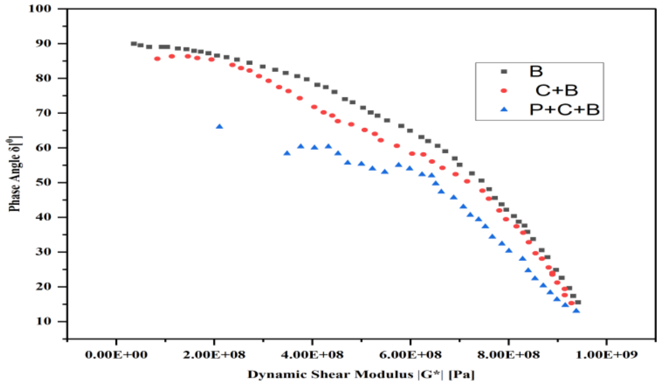

Fig. 4: Black diagram of bitumen (B), crumb rubber modified bitumen (C+B), and polymer crumb rubber modified bitumen (P+B+C)

Polypropylene-crumb rubber-modified bitumen displays a low phase angle with a flat region near 60 degrees. In comparison, both the reference bitumen and crumb rubber-modified bitumen exhibit higher phase angles at similar dynamic shear modulus values. The CRMB profile shows a slight deviation from the reference bitumen, suggesting interaction between the bitumen and crumb rubber particles [23-24]. A lower phase angle in polypropylene-modified bitumen relative to reference binders indicates improved elasticity and resistance to deformation, supporting its application in durable, high-performance asphalt pavements.

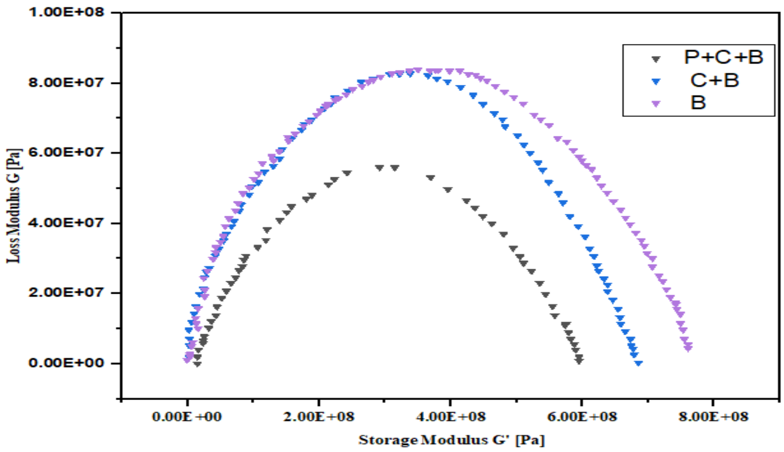

Fig. 5: Cole–Cole plots of bitumen (B), crumb rubber modified bitumen (C+B), and polymer crumb rubber modified bitumen (P+B+C)

Cole–Cole and related rheological diagrams indicate that increasing crumb rubber content typically enhances stiffness at elevated temperatures and improves rutting resistance, while also increasing resistance to low-temperature cracking. Cole–Cole plots illustrate the relationship between the storage modulus and loss modulus of bitumen, providing valuable insights into its viscoelastic properties [25]. The Cole–Cole plots for crumb rubber-modified bitumen (C+B) and polymer crumb rubber-modified bitumen (P+B+C) are presented. Figure 5 demonstrates that polypropylene-modified bitumen exhibits the lowest storage and loss modulus compared to both crumb rubber-modified bitumen and reference bitumen.

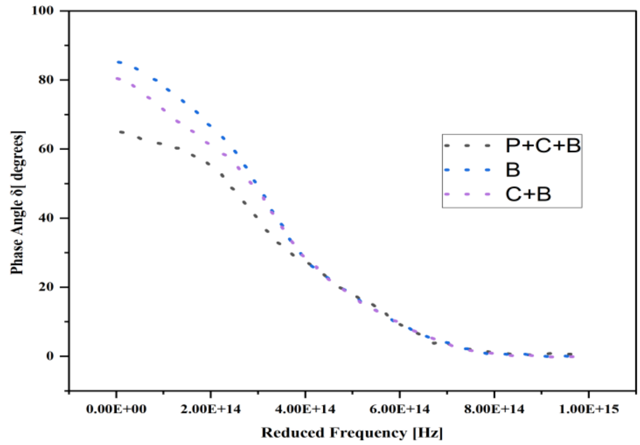

Fig. 6: Black diagram of the master curve at a reference temperature of 20°C of bitumen (B), crumb rubber modified bitumen (C+B), and polymer crumb rubber modified bitumen (P+B+C)

In the black diagram of the master curve shown in Figure 6, polypropylene crumb rubber-modified bitumen (P+C+B) exhibits the lowest phase angle at the specified frequency and temperature. This finding suggests that the sample can effectively relax stress and recover strain. Crumb rubber-modified bitumen (C+B) and the reference binder display similar, but higher, phase angles.

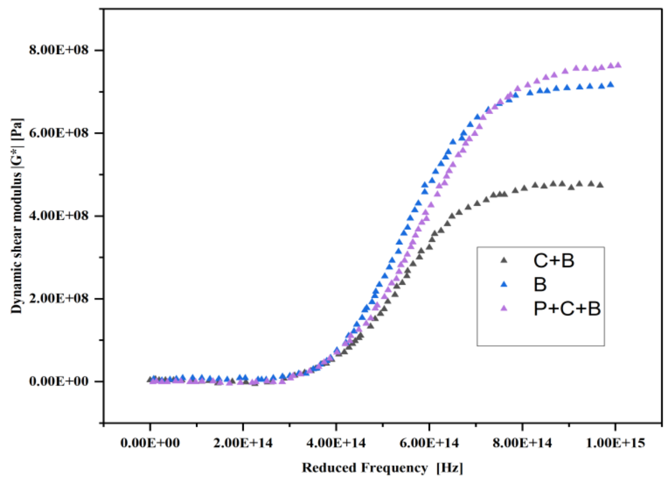

Fig. 7: Dynamic shear modulus master curves at a reference temperature of 20°C of bitumen (B), crumb rubber modified bitumen (C+B), and polymer crumb rubber modified bitumen (P+B+C)

Dynamic shear modulus master curves plotted against reduced frequency are essential for characterizing the viscoelastic behavior of polypropylene crumb rubber bitumen[26]. Both short- and long-term aging increases the modulus and decreases the phase angle, resulting in a stiffer and more elastic binder. The incorporation of polypropylene significantly enhances the dynamic shear modulus and elasticity of bitumen at lower frequencies, thereby improving resistance to rutting and temperature sensitivity. These results indicate that polymer-modified crumb rubber bitumen can be effectively utilized, reducing bitumen consumption and lowering road construction costs.

BBR results indicate that increasing the polypropylene and crumb rubber content in bitumen causes a slight increase in creep rate and a substantial reduction in stiffness [27]. Experimental data demonstrate that crumb rubber modification significantly enhances low-temperature flexibility, stress relaxation, and aging resistance of bitumen. Determining the optimal crumb rubber content is essential for maximizing these benefits while preserving workability and storage stability.

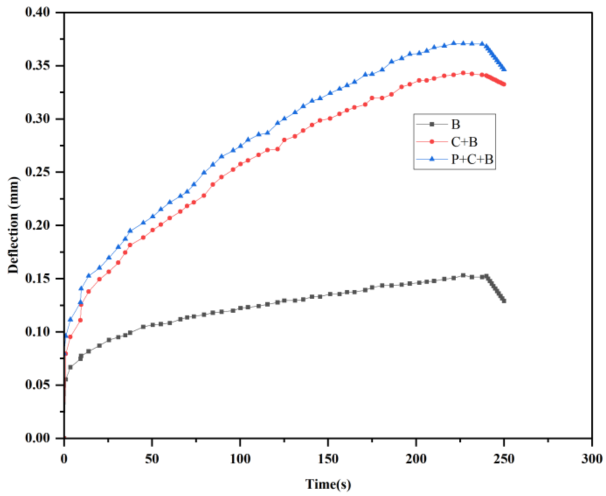

Fig. 8: Schematic deflection and load profile versus time for aged samples- bitumen (B), crumb rubber modified bitumen (C+B), and polymer crumb rubber modified bitumen (P+B+C)

4. CONCLUSIONS

The incorporation of polypropylene and crumb rubber into bitumen enhances both high- and low-temperature performance. Polypropylene increases stiffness and rutting resistance, while crumb rubber improves elasticity and resistance to cracking. Results from the Dynamic Shear Rheometer (DSR) and Bending Beam Rheometer (BBR) indicate that the addition of these modifiers produces a binder with a high complex modulus and a low phase angle, reflecting improved resistance to cracking and deformation. Overall, the modified binder exhibits superior viscoelastic properties, effective cracking resistance, and extended pavement durability.

5. DECLARATION OF COMPETING INTEREST

The authors declare that they have no competing interests. This research was supported by The Research Council (TRC), Ministry of Higher Education, Research and Innovation, Sultanate of Oman, grant number “MoHERI/BFP/UTAS/2023,

ACKNOWLEDGEMENT

We express our sincere gratitude to the Ministry of Higher Education, Research and Innovation (MoHERI), Sultanate of Oman, for its significant support and encouragement of this research. We also wish to thank the University of Technology and Applied Sciences (UTAS), Muscat, for offering the necessary facilities, resources, and academic environment that enabled the successful completion of this study.

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