

The Effect of Rubberized Materials on the Rheological Properties of Asphalt Binder

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ABSTRACT

Due to the high-performance capabilities of the asphalt mixture, Crumb Rubber (CR) and Styrene-Butadiene Rubber (SBR)-modified asphalt have been widely used to minimize the environmental impact of waste, including rubber. However, the structural workability and separation of the modified asphalt, as well as the high cost of the SBR-modified asphalt, pose serious challenges to its application. This leads to an investigation of the effects of CR and SBR additives on asphalt binders to determine their impact on the latter's physical and rheological properties. One type of 40/50 penetration-grade asphalt binder was used with two types of additives: CR and SBR at four percentages ranging from 3% to 12%, with each percentage increasing by 3%. The rheological properties of the asphalt binder were studied to evaluate the additive effects and the extent of improvement of the modified binders with and without short- and long-term aging. Both SBR and CR can improve the asphalt properties, but they have different effects, with SBR being more compatible with asphalt than CR. SBR, especially in hot-mix asphalt, improves the rutting resistance, while CR, which is derived from recycled tires, offers environmental and economic benefits, but it enhances the rutting resistance to a lesser extent.

Keywords-asphalt; rubber; crumb rubber; SBR modified asphalt; rheological properties

I. INTRODUCTION

Monitoring the growth of vehicle sizes, especially those used on highways, in developing countries has revealed a significant number of used tires. The estimated annual loss is 1.4 billion tires, with the material utilized in the rubber industry being one of the most dangerous and common types of waste when considering the high cost of production and short lifespan [1]. For this reason, recycled tires have been used in the production of improved asphalt for more than three decades. However, the problem of wasted tires has been worsened significantly. Therefore, there is a need to use Crushed Rubber Tires (CRT) in asphalt mixtures [2], as they provide many technical benefits and protect the environment from waste [3]. The use of CR-modified mixes has been increased significantly compared to roads built with conventional designs. Roads using Crushed Rubber-Modified (CRM) concrete are still performing well after several years of use. The impact of CR on Hot-Mixed Asphalt (HMA) has been examined. The results have revealed notable improvements in the development and enhancement of various asphalt properties. Additionally, research indicates that activation treatment improves the

compatibility between CR and base asphalt, resulting in better performance of the modified asphalt [4]. Integrating crushed rubber into asphalt, has increased the pavement durability and has enhanced the performance at high and low temperatures [5]. Furthermore, significant effects, such as reduced traffic noise, improved pavement performance, and lower cost, have been observed, making it a valuable additive to asphalt concrete [6]. The corrosion resistance of mixtures improved with high temperatures, in addition to their good resistance to cracking at low temperatures, has been compared to that of unimproved mixtures. The aging resistance of asphalt mixtures increased with the percentage of additives [7]. Incorporating crushed rubber into asphalt provides an eco-friendly waste management solution because CRMs enhance the properties of HMA. Additionally, using CRMs extends the longevity of the road surfaces by reducing the effects of traffic loads on pavements [8]. The environmental benefits are notable because the recycling of waste tires is increased, while their ecological footprint is reduced. Using CR in the HMA production also reduces the air pollution, decreasing the carbon monoxide (CO) and methane (CH₄) emissions by 39.7% and 61.7%, respectively. Furthermore, adding CR to flexible pavements

can improve the noise reduction features [9]. Authors in [10] showed the potential of producing high-quality asphalt binders using different types of polymers. There are two ways to prepare asphalt modified with various polymers: mechanical mixing or chemical reaction techniques. Styrene-butadiene-styrene (SBS), SBR, Polyethylene (PE), and CR are among the polymers used to modify native asphalt and enhance the cohesion of road pavements. Authors in [11] highlighted the importance of selecting the type and content of polymers in asphalt because it significantly affects the durability of the asphalt pavements. Authors in [12] examined the superior quality of asphalt concrete pavement modified with SBR. Some of the most important advantages have been proven, including:

- A direct and positive impact on the plasticity values, especially at low temperatures
- Increased viscosity
- Improved resilience

This additive consists of approximately 75% styrene and 25% butadiene bonded together in a copolymer. The most important features of SBR polymers are the improved bonding and mixing ability, enhanced wear resistance and durability, and a significant increase in viscosity, allowing for additional flexibility [5]. It has been found that increasing the SBR content to 3-5% improves the overall performance. This study evaluates the physical and rheological properties of asphalt binders modified with rubber materials, such as CR and SBR polymers, with the tests being conducted in accordance with international specifications.

II. MATERIALS

The materials used in this research are commonly used in the asphalt paving industry. The asphalt has a penetration of 40-50 and contains CR and SBR at percentages ranging from 3% to 12% of the asphalt's weight, according to the SBR specification [6].

A. Asphalt Cement

This study examined the properties of added polymeric materials and their effect on the properties of asphalt binders from the Thi Qar Refinery, as shown in Table I.

TABLE I. PHYSICAL PROPERTIES OF ASPHALT BINDERS

Tests	Standard	Results
Penetration, (25°C, 5sec., 100gm)	ASTM D5	48
Softening point, °C	ASTM D 36	54
Ductility at 25°C	ASTM D 113	122
Specific gravity	ASTM D 70	1.03
Flash point (°C)	ASTM D92	288
Fire point (°C)	ASTM D92	320
Brook-field viscosity at 135 C°	ASTM D-4402	0.625
Brook-field viscosity at 165 C°	ASTM D-4402	0.22

B. Styrene Butadiene Rubber

SBR is a synthetic rubber made from styrene and butadiene, known for its durability and long-term stability. Table II provides details on the physical properties and chemical composition of the specific SBR used.

TABLE II. PHYSIOCHEMICAL PROPERTIES OF SBR STYRENE BUTADIENE RUBBER

Tests	Results
Polymer structure	Elastomers
PH	9-10.5
Specific gravity	1.01
Compressive strength	40 MPa
Tensile strength	6.5 MPa
Flexural strengt	13 MPa
Solid content	75% Butadiene, 25% Styrene
Brook-field viscosity at 165 C°	0.22

C. Crumb Rubber

To ensure optimal outcomes, high-quality shredded rubber (40 mesh) was employed, as it is derived from used and discarded tires. The material properties of the product comply with the restrictions set forth by the ROHS regulations. A key feature of T-MESH 40 modified CR is its purity, as it is free from external contaminants. As displayed in Table III and Figure 1 the study uses CR as a primary research material.

TABLE III. PHYSICAL CHARACTERISTICS OF RECYCLED TIRE CRUMB RUBBER

Tests	Standards	Results
Passing %	ASTM D5644	> 90
Heat loss %	ASTM D1509	< 1
Metal contents %	ASTM D5603	≤ 0.10
Fiber contents %	ASTM D5603	≤ 0.30



Fig. 1. CR used.

III. PRODUCTION OF BINDER MODIFIED WITH RUBBERIZED MATERIALS

The usage of rubber, aluminum, and plastic has become standard practice in all engineering fields, aiming to reduce the adverse environmental effects of these materials, in addition to enhancing the characteristics of the structures to which they are applied. In order to obtain a rubber-modified asphalt with high homogeneity, the rubber material was mixed with an asphalt binder with a percentage of (40-50) at temperatures ranging between 160 °C-170 °C and a cutting speed of 1000 rpm for a duration of 1 h [10, 13]. Following the preparation of the modified asphalt, its distribution was conducted in the designated basins for the preparation of the subsequent asphalt tests.

IV. RESULTS AND DISCUSSION

All physical and rheological tests, including the softening point, penetration, viscosity, and DSR, were performed sequentially on the bituminous binder, both with and without the addition of rubberized additives. These tests were performed in accordance with the specifications of the ASTM standards.

A. Penetration and Softening Point Test

Figure 2 presents the outcomes of the rubberized asphalt tests, along with the percentage of additives, penetration values, and softening point for the ratios used in the study. A substantial decline in the liquefaction value was observed, concurrent with a persistent rise in the rubberized additive ratios for both categories. The proportion of the rubber materials in the mixture directly correlates with the penetration values, with higher proportions resulting in lower values. This indicates that the binder becomes more rigid and stable [14]. Additionally, the modified asphalt binders exhibit lower penetration values compared to their pure counterparts [15].

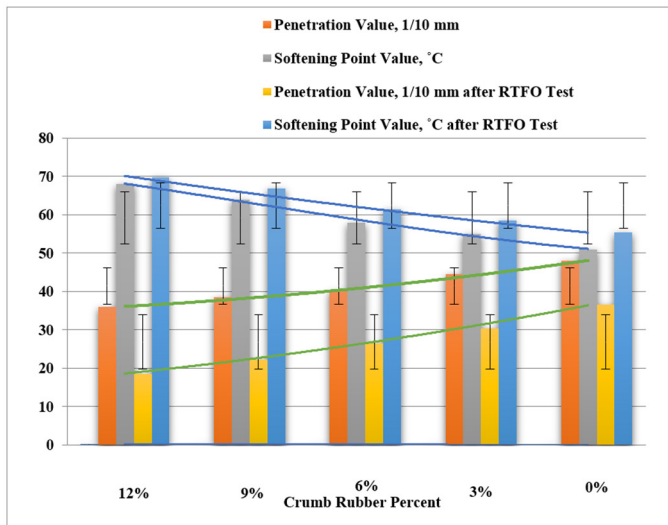


Fig. 2. Penetration and softening value for modified asphalt with rubberized materials.

B. Potential Viscometer Test

One of the most significant additives that enhance the viscosity of the asphalt binder is the addition of rubber components. The integration of SBR rubber and CR enhances the viscosity of the materials, thereby improving their overall performance. It is important to acknowledge that elevated viscosity impedes the workability during the preparation process [14]. Figure 3 portrays the rotational viscosity results for both the SBR and CR modifiers at two distinct temperatures, 135°C and 165°C. The impact of both additives, denoted by CR and SBR, on the viscosity of the modified asphalt binder was substantial across all used proportions. The rotational viscosity results show that:

- When subjected to testing at a temperature of 135°C, the rotational viscosity of SBR-modified asphalt cement (3%, 6%, 9%, and 12%) exhibited an expansion of 58.13%,

162.58%, 207.79%, and 245.25%, respectively. Similarly, at a temperature of 165°C, the rotational viscosity increased to 29.9%, 63.08%, 92.06%, and 123.83%, respectively. While the CR modification expanded to 24.4%, 50%, 97.55%, and 137.88% at 135°C, while at 165°C, it increased to 22.4%, 50.94%, 64.02%, and 86.45%, respectively.

- The addition of rubber additives leads to a substantial enhancement in viscosity. Consequently, the workability of the modified asphalt binder became more difficult, requiring increased mixing temperatures and pressures.
- As the temperature increased, the viscosity of the asphalt binder decreased.

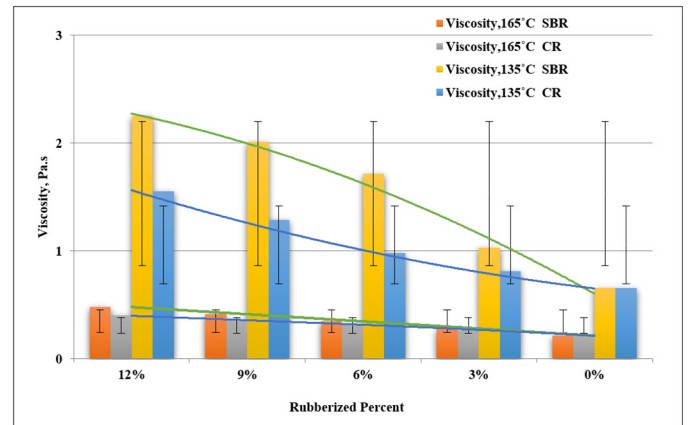


Fig. 3. Increases in the viscosity percentage for rubberized materials at 135 and 165 C°.

C. The Rheological Characteristics of Rubberized-Modified Asphalt Binders

Figures 4 and 5 present the outcomes of DSR testing at elevated operating temperatures ranging from 40 °C to 82 °C, with a tolerance of 6 °C. It was observed that SBR and CR exhibited analogous effects, despite their different values, on aged asphalt binders. The SBR material showed an improvement in the failure temperature of 9%, while the CR material exhibited an enhancement of 6.0%. These findings suggest that ZGSB exhibited superior efficacy in the softening of aged asphalt binders when compared to SBR. The key factor in this consideration is the enhancement of asphalt binder viscosity that is observed upon the incorporation of rubber additives.

The SBR modification significantly alters the rheological properties of asphalt cement. SBR enhances the asphalt's resistance to permanent deformation (rutting) and improves its elasticity and flexibility, particularly at low temperatures. These alterations are considered to be the result of the formation of a three-dimensional network structure within the asphalt binder when SBR is incorporated. Figures 6 and 7 demonstrate that the rubberized additives have a significant impact on the elasticity of the asphalt binder following RTFO testing.

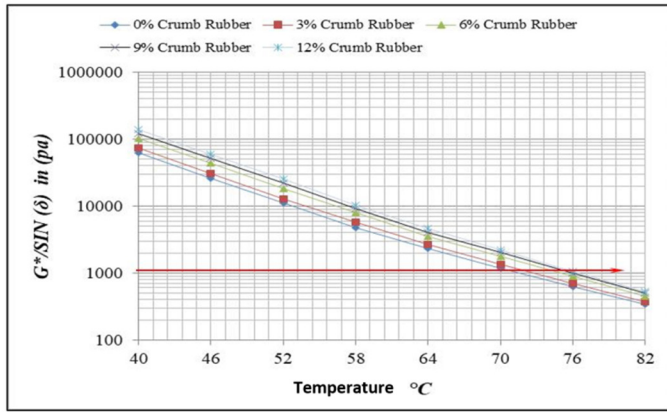


Fig. 4. Temperature sweep test for CR modified binder.

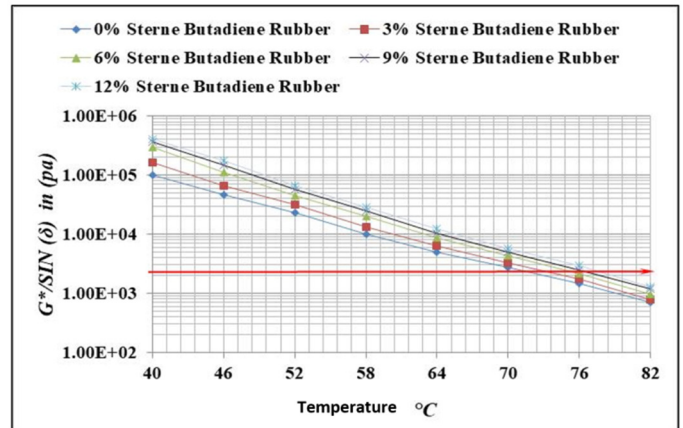


Fig. 7. Temperature sweep test after RTFO-aged for SBR modified binder.

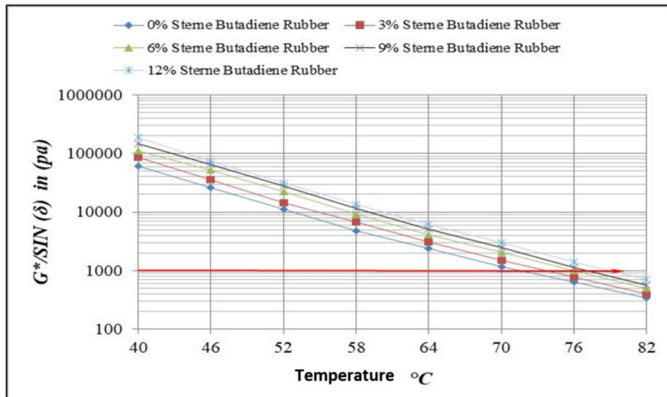


Fig. 5. Temperature sweep test for SBR modified binder.

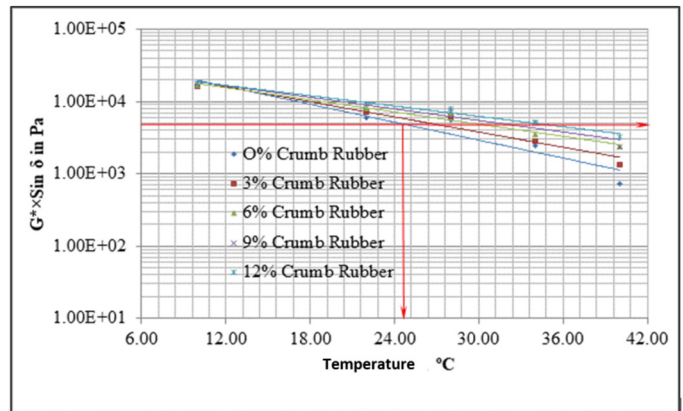


Fig. 8. Temperature sweep test for CR modified binder at different rates.

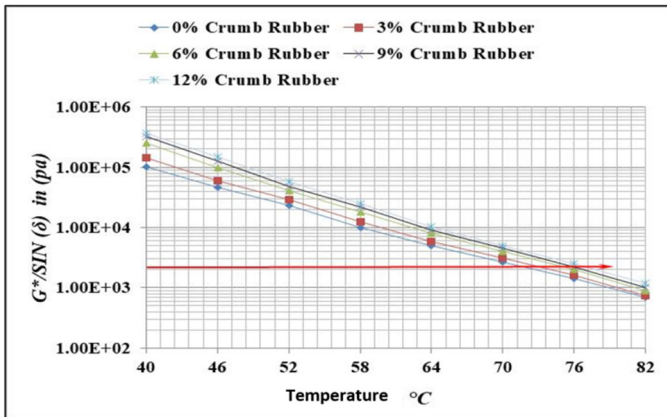


Fig. 6. Temperature sweep test after RTFO-aged for CR modified binder.

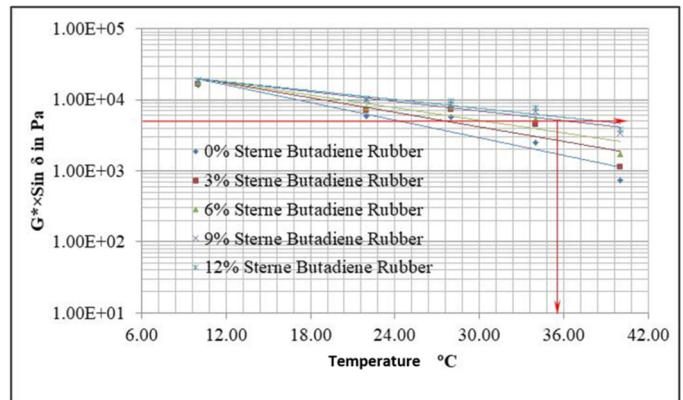


Fig. 9. Temperature sweep test for SBR -modified binder time sweep test at various proportions.

The time scanning technique was followed in a similar manner to the asphalt fatigue test, using a DSR device to evaluate the modified asphalt binder. This test is considered to be the ideal method for monitoring the development of asphalt binder over time, as shown in Figures 8 and 9.

It is important to increase the failure temperature in order to enhance the performance of the asphalt binders. This procedure reduces the cracking and deformation that are often observed in asphalt pavement due to the exposure to elevated temperatures. Table IV presents a comparison of the respective rubber-modified binders at four different ratios, along with their breakdown temperature and PG classification.

TABLE IV. FAILURE TEMPERATURE OF RUBBERIZED MATERIAL-MODIFIED BINDER AND PG- GRADING

Binder's type	Failure temperature C°			Highest temperature PG - grading
	Un-aged	RTFO-aged short-term aging	PAV aged long-term aging	
MB-R0	71	72	24.5	PG 70
MB-CR3	72.5	73.2	26	PG 70
MB-CR6	74.5	74.6	28	PG 70
MB-CR9	75.7	76.2	31	PG 70
MB-CR12	76.3	77	34	PG 76
MB-SBR3	73.5	73.3	27	PG 70
MB-SBR6	76	75.1	29.5	PG 70
MB-SBR9	77.2	77	35.5	PG 76
MB-SBR12	79	77.8	37	PG 76

V. CONCLUSIONS

The primary objective of this study is to demonstrate the effect of rubberized materials, such as Crumb Rubber (CR) and Styrene-Butadiene Rubber (SBR), on the properties of asphalt binder and its suitability for use in terms of permeability, viscosity, etc. The test results proved that: the integration of SBR within the composition of asphalt cement exerts a substantial influence on the rheological and physical properties of the resulting material, in conjunction with the incorporation of CR. Additives were incorporated into the asphalt cement at concentrations ranging from 3% to 12%, resulting in an increase in the asphalt weight of 3%. This modification of the asphalt binder is employed in highway paving, enhancing the performance and prolonging the service life. The following conclusion can be drawn:

- The use of rubberized materials of both types, CR and SBR, as modifiers, enhances the properties of the binding material, by decreasing the permeability and increasing the softening point values. The addition of rubber materials leads to enhanced resistance to deformation.
- The impact of aging on the bond's integrity and volume fraction was evident through the permeability test results, which revealed the effects of the heat and air exposure following the thin film furnace test.
- The modification of the asphalt binders with rubberized materials exerts a substantial influence on the rotational viscosity values, with an increase in the proportions of rubber additives. Consequently, the viscosity of the asphalt mixture increases, and the permanent deformation is reduced, in comparison to conventional asphalt binders.
- This enhanced abrasion coefficient was observed when both types of rubberized materials were mixed with the bitumen, thereby increasing the rubber paving mixture's resistance to abrasion.
- In the field of asphalt technology, the impact of rubber improvers on the aging process is substantial, by enhancing the performance of the resulting material when compared to the original, unimproved asphalt. This enhancement is particularly evident in terms of the modified asphalt's resistance to cracking and abrasion.

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