Enhancing Asphalt Mixture Performance with Crumb Rubber: A Sustainable Solution for Improved Durability and Mechanical Properties

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Abstract. Asphalt crumb rubber is a type of pavement material formed by mixing asphalt cement with crumb rubber that is derived from recycled tires. This eco-friendly approach aids in waste reduction and promotes environmental preservation by incorporating recycled materials into pavement construction. The study aimed to examine the behavior of asphalt mixtures modified with crumb rubber, made by blending recycled tire-derived crumb rubber with asphalt cement. Adding crumb rubber improved the performance of asphalt mixtures, with 8% crumb rubber enhancing the Marshall stability by 20% and 34% for 40/50 and 50/60 grades, respectively. The moisture susceptibility of both grades also improved. Crumb rubber is a sustainable material that can improve the performance of asphalt mixtures.

Keywords: Crumb rubber; asphalt mixtures; bitumen.

1 INTRODUCTION

The use of crumb rubber in asphalt has been widely investigated in recent years as a sustainable and cost-effective approach to improve the performance and durability of asphalt pavements. Crumb rubber is obtained from the recycling of scrap tires and can be used as a partial replacement of asphalt binder or as a modifier of asphalt mixtures. Several studies have shown that adding crumb rubber to asphalt mixtures can improve their mechanical, rheological, and moisture-resistance properties. Crumb rubber can enhance asphalt mixtures' stiffness, fatigue, and rutting resistance, reducing their susceptibility to moisture damage and environmental aging. The improved performance of crumb rubber-modified asphalt mixtures can be attributed to the unique properties of crumb rubber, such as its high elasticity, low glass transition temperature, and high viscosity at high temperatures.

Adding crumb rubber to asphalt improves its fatigue resistance [1]. The conclusion reached: crumb rubber has a positive impact on Increasing Protection against Fatigue Crumb rubber is suitable because it can create a uniform mixture and prevent asphalt mixtures from settling due to its small particle size. Several studies show that adding crumb rubber to asphalt makes it work better, with less cracking and more fatigue life, strength, and resilience viscosity and adhesion [2-9]. The recycling of tires results in a cheaper product, crumb rubber CR which helps with the problem of solid waste management. Over the past few years, numerous experimental studies have been conducted to assess and enhance the design philosophy, properties, specifications, and materials applied in asphalt rubber production [8,9].

A study conducted by Al-Fayyadh and Al-Mosawe [8] investigated the effect of short-term aging on Warm Mix Asphalt (WMA) that has different percentages of rubber. They found that adding crumb rubber generally improves the resistance to moisture compared with WMA without rubber, but the resistance starts to decrease as the rubber content increases to 2%. Another study performed by Lushinga et al. [4] examined the use of crumb rubber in hot mix asphalt concrete and found that it can be added without negatively affecting pavement performance as long as the mixture is made and put down properly. Asim [10] investigated the effect of adding crumb rubber to a stone matrix asphalt (SMA) mixture and found that adding 12% of the bitumen's weight in Crumb rubber CRM was the optimal amount to improve the resilient modulus of modified SMA samples.

The study's objective is to assess the impact of adding crumb rubber to asphalt mixtures in terms of its mechanical, rheological, and moisture resistance characteristics. The researchers aim to identify the ideal crumb rubber dosage and processing conditions and evaluate the modified asphalt mixtures' durability, mechanical properties, and moisture sensitivity.

2. MATERIALS

2.1 Crumb Rubber

Crumb rubber is made by shredding old tires, which is a unique material that doesn't have any fibers or steel in it. Rubber particles come in different sizes and shapes and can be sorted by size. The crumb rubber used in this research was obtained from Aldiwaniya, and its properties are shown in Table 1 below.

Table 1: Crumb rubber properties.

Property	Unit	Value	ASTM Specifications
Sp.gravity	gm\cm^3	1.1-1.3	(D297)
Ash content	%	5-15	(D297)
Heating loss	%	1	(D1509)
sieve anylasis	%	90	(D5603)
fiber content	%	0.5	(D5603)
steel content	%	0	(D5603)

2.2 Aggregate

In this project, the researchers used aggregate from Al-Nibaie quarry, composed of tough crushed quartz with no damaging substances like clay or loam. This type of aggregate is commonly used in Baghdad for both asphalt and concrete mixes. The aggregate particle sizes varied from ¾ in. (19 mm) to sieve size No.200 (0.075 mm) to meet the necessary gradation specifications. The aggregate physical properties are shown in Table 2.

Table 2: Physical properties of aggregate.

Property		Value	ASTM Designation No.
Coarse aggregate	Bulk specific gravity	2.584	ASTM C 127
	Apparent specific gravity	2.608	ASTM C 127
	Water absorption %	0.57 %	ASTM C 127
	Wear % (Los Angeles abrasion)	13.08 %	ASTM C 131
Fine aggregates	Bulk specific gravity	2.646	ASTM C 128
	Apparent specific gravity	2.687	ASTM C 128
	% water absorption	1.419 %	ASTM C 128

2.3 Asphalt Binder

This study used Daura asphalt cement types with penetration grades of (40-50) and (50-60) were used. Table 3 displays the original asphalt cement's physical characteristics.

Table 3: Asphalt cement physical characteristics.

Property	Unit	Asphalt (Daura)		Specifications	
		(40_50)	(50_60)	(40_50)	(50_60)
Penetration (25˚C, 100 gm, 5 sec) ASTM D 5	0.1 mm	45.26	56.23	40_50	50_60
Ductility (25˚C, 5 cm/min) ASTM D 113	cm	126	146	>100	>100
Flashpoint (cup for cutting open land) ASTM D 92	(in ◦C)	>250	>250	>232	>232
Softening point	(◦C)	50	48	--------	--------

2.4 Preparing Test Specimens

The study used a range of 4 to 5.2% binder based on the total weight of the mixture, and the aggregate particles were dried at 110 degrees Celsius. Different percentages of crumb rubber CR were added to two binder grades through a wet process to create the modified asphalt cement. The mixture was produced using a high-shear mixing blender at 1000 rpm for 15 minutes at 175℃. The CR content added to the binder was 0, 2, 4, 6, and 8%. Laboratory specimens of the asphalt mixture were then prepared using the selected aggregates and asphalt binder using a Marshall compactor to apply compaction force to the mixture. The compacted samples are shown in Figure 1.

Figure 1: Compacted samples.

3 RESULTS

3.1 Asphalt Cement

Standard tests were carried out on the modified asphalt binder, and the results are presented in Figure 2, which shows the penetration test results for the modified asphalt binder with varying CR contents. The results demonstrate that the inclusion of CR reduced the penetration values.

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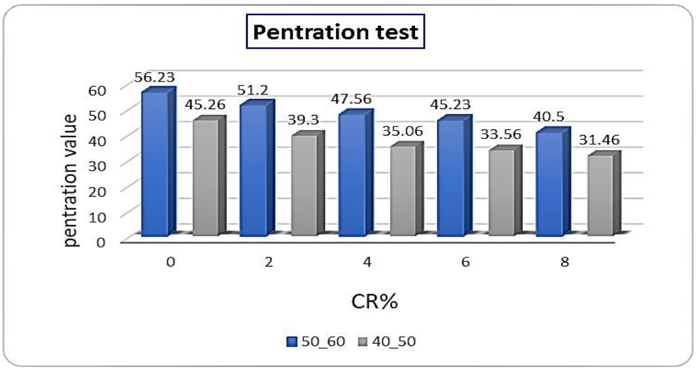

Figure 2: Penetration test results for the two types of asphalt binder modified with crumb rubber.

The results of the softening point and ductility tests for the modified asphalt binder are presented in Figures 3 and 4. The addition of crumb rubber to the asphalt cement increased the softening point values and decreased the ductility values. The increased softening point values indicate that the binder became stiffer with the addition of rubber, which requires a higher temperature to soften and flow. The decreased ductility values are attributed to the stiffer binder caused by the rubber content, which reduces the ability of the asphalte to stretch and deform under traffic loads.

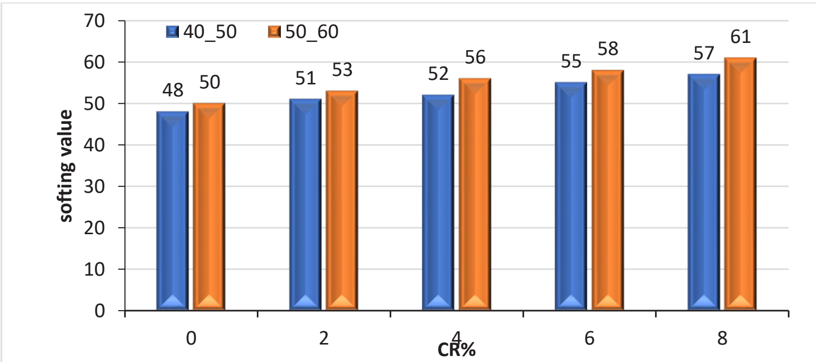

Figure 3: Softenning point test results for modified asphalt binder with CR.

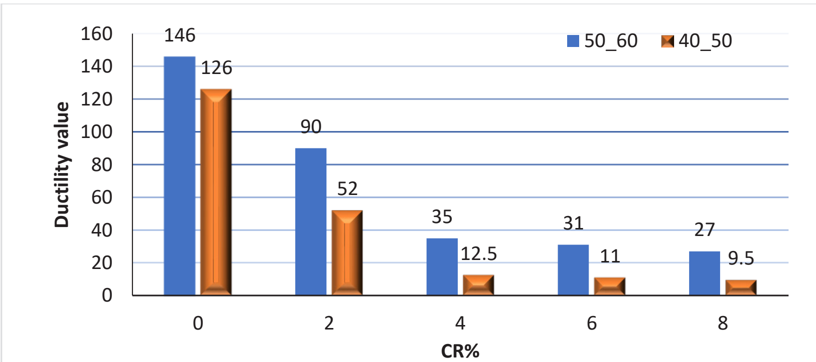

Figure 4: Ductility test results for modified asphalt binder with CR.

3.2 Marshall Properties

The Marshall design method determined the optimal binder content for each percentage of crumb rubber and for both types of binders. The test results in this section relate to samples made with the optimal binder content.

Tables 4 and 5 display the results for the Marshall properties when adding four different percentages of crumb rubber to the two types of asphalt binders used in the asphalt mixtures.

Table 4: Marshall characteristics at optimum (40/50) binder contents.

%CR	Optimum binder content (%)	Void (%)			Marshall stability (kN)	Flow value (mm)	Bulk density
		VIM	VMA	VFA			
0	4.6	4.29	14.42	70.25	11.23	3.5	2.371
2	4.7	4.91	13.80	64.42	12.3	3.42	2.378
4	4.8	4.65	13.46	65.47	12.6	3.31	2.382
6	4.9	3.28	12.22	73.18	13.2	3.23	2.41
8	5.0	3.13	12.08	74.10	13.5	3.18	2.43

Table 5: Marshall characteristics at optimum (50/60) binder contents.

%CR	Optimum binder content (%)	Void (%)			Marshall stability (kN)	Flow value (mm)	Bulk density
		VIM	VMA	VFA			
0	4.6	3.79	13.9	72.73	9.5	4.5	2.36
2	4.7	4.22	13.07	67.73	11.42	4.1	2.38
4	4.8	3.67	12.58	70.80	11.78	3.8	2.39
6	4.9	3.50	11.94	75.14	12.32	3.5	2.41
8	5.0	3.00	11.06	81.92	12.74	3.1	2.43

The graph in Figure 5 shows that the inclusion of CR in the mixture caused an initial increase in air voids compared to the 0% CR mixture, followed by a decrease. Surprisingly, when using a 50/60 binder grade, adding CR led to an air void content lower than the required limits of 3-5%. This decrease in air voids makes the mixture more likely to experience bleeding in high temperatures and under heavy traffic loads.

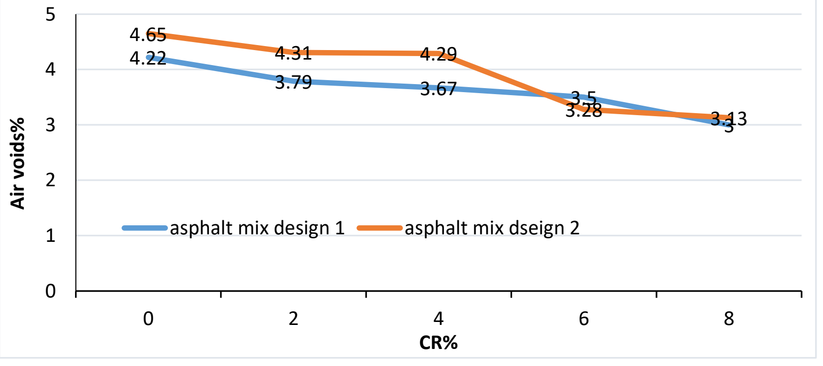

Figure 5: Percent of Air voids variation when adding CR.

The use of crumb rubber in asphalt mixtures has a significant effect on the Marshall Stability of the resulting asphalt. Marshall Stability measures the maximum load an asphalt mixture can bear, making it a vital indicator of pavement strength and durability. Figure 6 displays the Marshall Stability test results of mixtures with modified binder content containing CR. The addition of crumb rubber to asphalt mixtures increased their Marshall Stability. This is due to the rubber particles acting as a reinforcement agent, which enhances the cohesion and adhesion of the asphalt mixture, improving its load-carrying capacity.

Incorporating crumb rubber in asphalt mixtures can also affect the Marshall flow of the resulting mixture. Marshall flow measures the extent of deformation or flow of the asphalt mixture under a particular load and temperature condition. As depicted in Figure 7, adding crumb rubber to asphalt mixtures leads to a decrease in the Marshall flow of the mixture. This is likely because the rubber particles act as a strengthening agent, improving the bonding and cohesion of the asphalt mixture and boosting its resistance to deformation and flow.

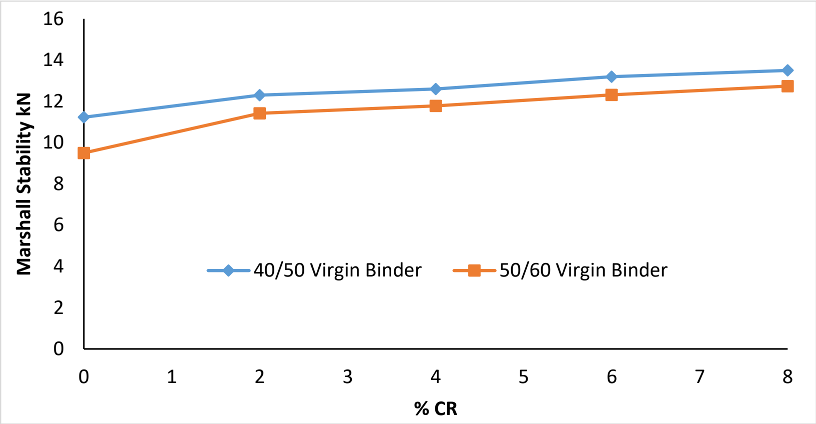

Figure 6: Marshall stability variation when adding CR.

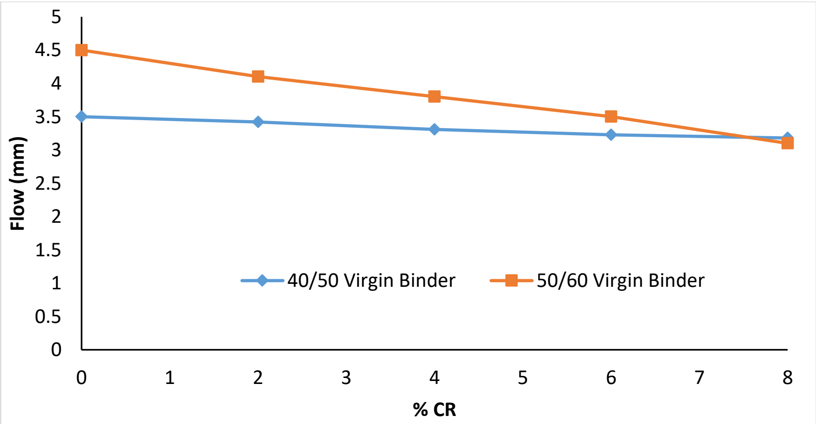

Figure 7: Marshall flow variation when adding CR.

3.3 Moisture Susceptibility

The study utilized the indirect tensile test, a widely used laboratory test to assess the tensile strength and stiffness of asphalt mixtures. The test involves subjecting a cylindrical asphalt mixture specimen to a tensile force in a diametrical direction perpendicular to its axis. The test was conducted following ASTM D4867. All specimens were compacted to achieve (7±1)% air voids, typical of field void levels within 6-8% of air voids. Multiple experiments with different compaction blows determined the required number of blows for achieving the target air void percentage. For the wet subset, the specimens were saturated with distilled water at room temperature using a vacuum chamber to reach a 55-80% saturation degree. The partially saturated specimens were soaked in distilled water at (60±1) °C for 24 hours before being temperature-adjusted to (25±1) °C for 1 hour before the test. For the dry subset, the specimens were soaked in a water bath for 20 minutes before the test to adjust the temperature to (25±1) °C.

All specimens were subjected to an ITS test at a constant loading rate of 50 mm/min at 25 °C until they failed due to vertical deformation. The maximum load was recorded to determine the tensile strength of all specimens. To evaluate the moisture sensitivity of the mixtures, the tensile strength ratio (TSR) was determined by dividing the conditioned strength by the unconditioned strength. ASTM D4867 (2014) states that a TSR value of at least 80% indicates adequate moisture resistance. Adding crumb rubber to asphalt mixtures enhances their resistance to moisture damage, as the TSR value indicates. The TSR values for asphalt mixtures containing crumb rubber are usually higher than those of conventional asphalt mixtures. This improvement in moisture resistance is attributed to the rubber particles filling the voids in the asphalt mixture, which helps to prevent water from penetrating the mixture and reduces the stripping of the asphalt binder from the aggregate. See Figure 8.

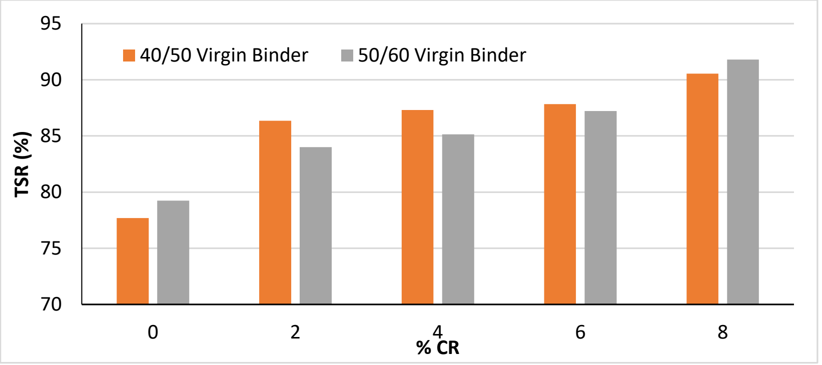

Figure 8: Tensile strength ratio variation when adding CR.

5. CONCLUSIONS

In summary, this study reveals that including crumb rubber in asphalt, mixtures can positively affect their mechanical and durability properties, such as Marshall stability, flow, and rutting resistance. It can also improve the properties of the asphalt binder, such as viscosity, ductility, and softening point. Nonetheless, the efficacy of crumb rubber depends on various factors, including the size and source of the rubber particles, the properties of the asphalt binder, and the mixing and compaction conditions. Thus, selecting the appropriate crumb rubber source and size is crucial, and optimizing the mixing and compaction conditions to achieve the desired improvement in the asphalt mixture performance. The study recommends an optimum addition of 4% CR to 40/50 binder grade and 2% CR to 50/60 binder grade due to VMA limitations. Overall, the research suggests that using crumb rubber can be a sustainable and cost-effective approach to improve the performance and durability of asphalt pavements and promote the recycling and reuse of waste materials.

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