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Experimental study of sustainable asphalt mixtures containing waste materials

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Abstract: In the past decade, there has been a significant increase in traffic density and axial load, which has resulted in the road's rapidly deteriorating condition. Therefore, it was imperative to identify solutions to these issues to enhance the asphalt mixture to withstand excessive loads and weather fluctuations and extend the periodic maintenance period. This research aims to examine the performance characteristics of the asphaltic mixture by incorporating RAP and crumb rubber derived from waste tires and to compare the enhanced and conventional mixtures, regarded as the best sustainable solution the world is currently pursuing. Because crumb rubber is derived from discarded tires, which are difficult to dispose of and cause environmental pollution, this research has incorporated four proportions of crumb rubber (2%, 4%, 6 and 8%) into the 50-60 penetration grade asphalt binder. To achieve the optimal asphalt content and prepare laboratory samples for various laboratory tests, replace 10% of virgin aggregate gradation with RAP using the Marshall method for a wearing course. The outcomes demonstrated the improvement of modified mixtures with crumb rubber contents in the indirect tensile strength (ITS), moisture damage, rutting resistance, and Marshall stability and flow of asphaltic mixes.
Keywords: *Crumb rubber modifier, Reclaimed asphalt pavement, Sustainable asphalt mixtures and hot mix asphalt, Waste materials.*

1. Introduction

Reclaimed asphalt pavement (RAP) is utilized as an alternative to natural aggregate and binder, which is why it is termed "recycling of aged asphalt pavement". Implementing RAP in mixtures can reduce the consumption of Energy, mineral usage, costs, and relevant pollution(Akbas & Yuhana 2021; Gao et al. 2022; Li et al. 2022). Using RAP can decrease by up to 35% for gas emissions and 70% for production costs(Li et al. 2019; Akbas & Yuhana 2021; Alsolieman et al. 2021; Gamage et al. 2022; Gao et al. 2022; X. Wang et al. 2022). However, the utilization of RAP is still restricted in numerous countries due to inadequate awareness and nonstandard recycling requirements(Alsolieman et al. 2021; Zhang et al. 2022). European Asphalt Pavement Association (EAPA) Statistics illustrate that recycled hot-mix asphalt mixture (RHMA) was produced using 47% of RAP in Europe (Formela 2022). According to the National Asphalt Pavement Association (NAPA), asphalt applications utilize 84% of RAP in the United States(Duan et al. 2022; Formela 2022). Thus, it is imperative to evaluate RHMA's performance to guarantee its environmental and economic benefits. Crumb Rubber is produced from waste tires. Modified Asphalt with Crumb Rubber exhibits a higher viscosity at high temperatures than conventional asphalt binders, resistance to high stress and deformation resulting from traffic load, and lower stiffness at low temperatures than traditional asphalt binders(Ziari, Goli & Amini 2016; Picado-Santos, Capitão & Neves 2020; Tan, Zahran & Tan 2022; T. Wang et al. 2022). Conversely, at low temperatures exhibits exceptional resistance to low-temperature cracking. Crumb rubber absorbs the maltenes in the asphalt binder, thereby increasing the asphaltenes ratio by swelling 3–5 times its original size when added to an asphalt binder(Chen et al. 2020; Jin et al. 2021). This enhancement in the asphaltenes ratio improves asphalt binders' performance, provided that the mixing process (dry or wet),

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quantity of materials, and their quality are optimized, and mixing conditions are also optimized(Yang et al. 2017; Liu et al. 2022). It has been demonstrated that the application of CRM to asphalt binders improves their physical and rheological properties and their resistance to thermal cracking, fatigue, and rutting deformation. According to recent researches, the global tire disposal rate is approximately 2 billion tires annually (Wang et al. 2018; Dong et al. 2019; Liang et al. 2020; Mohammed & Joni 2024a). This constitutes two to three percent of the total volume of industrial waste. Vehicle sales are increasing in tandem with the global population, particularly in developing nations with greater vehicle access (Lo Presti 2013; Chen et al. 2019). Additionally, the volume of discarded tires increases due to prolonged commuting exposure, necessitating additional tires replacement (Czajczyńska et al. 2017; Chen et al. 2019). As a consequence, the environment is subjected to a substantial risk due to the rapid rise in the quantity of discarded tires. Tires are still being improperly handled despite government regulations and resource conservation initiatives. The leaching of contaminants into the atmosphere, ground, and water is standard in tires after they are stored in landfills, which can result in environmental disruption. The exposure of used tires to sunlight can result in the release of carbon dioxide into the atmosphere. This carbon dioxide contributes to increased air pollution, which may also contribute to climate change (Diab & You 2017; Rath et al. 2019a). The incorporation of recycled materials and enhanced binders in pavement construction diminishes construction costs and mitigates flexible pavement distresses (Shen, Li & Xie 2017; Leng, Padhan & Sreeram 2018; Brasileiro et al. 2019; Rath et al. 2019a; Rath et al. 2019b; Yang et al. 2019; Rodríguez-Fernández et al. 2020; Al-Soudany et al. 2023; Mohammed & Joni 2024b). Numerous studies have demonstrated that incorporating RAP enhances stiffness, thereby improving the Marshall stability value of mixtures relative to original mixtures. Additional investigations revealed that the utilization of waste materials, such as tire rubber, in asphalt mixtures could mitigate the necessity for new raw materials for road pavements and enhance their performance. The objective of the investigation is to evaluate the mechanical, rheological, and moisture resistance properties of asphalt mixtures modified with crumb rubber incorporated with RAP. As well as to determine the optimal crumb rubber dosage and processing conditions.

1.1. Description of the Materials

This research utilizes four primary materials to prepare asphalt mixtures composed of Asphalt cement (binder), Aggregate, crumb rubber and RAP. The binder of a 50-60 penetration grade brought from the Dourah refinery. The aggregate materials used were of a limestone type provided from the AL-Nibaie quarry; their characteristics are organized in Table 1.

Table 1.
The physical appearance of aggregates.

Property	Results	ASTM standard
Fine aggregate		
Bulk specific gravity	2.574	
Apparent specific gravity	2.617	C128
Water absorption (%)	0.72	
Coarse aggregate		
Bulk specific gravity	2.615	
Apparent specific gravity	2.630	C127
Water absorption (%)	0.88	
Los Angeles abrasion	18.0	C131
Angularity (%)	96	D 5821
Soundness (%)	3.1	C88

The recycled tires were shredded and sieved to produce crumb rubber powder, which was then mixed into the asphalt as an additive. The powder was obtained from local manufacturing facilities in Baghdad as in Figure 1. The passing percentage of crumb rubber powder through sieve no. 50 and sieve

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no. 200 are 3% to 0.7%, respectively. Table 2 illustrates some physical characteristics of crumb rubber used.

Table 2.
Performance requirements and test results of crumb rubber *.

Property	Result	Specification
Hardness (N)	70	≥55
Density (g/cm^3)	1.3	-
Carbon black (%)	30	25–38
Impurity (%)	0.38	<0.75
Slender flat (%)	7.5	≤10

Note: * According to results from tires industry company.

Figure 1.
Image of crumb rubber powder.

RAP was collected from the Mayoralty of Baghdad project office by milling a surface layer. After the solvent extraction test was conducted using a centrifuge extractor by ASTM D2172, the asphalt content of several samples of the RAP stockpile was 3.9 %. Table 3 illustrates the RAP aggregate gradation and compares it to the limitation of a standard wearing mixture according to (SCRB/R9) [18].

Table 3.
Test results of RAP aggregate gradation extracted.

Sieve size,	Gradation of passing percentages after extraction	SCRB, standards
¾	100	100
½	93	90 – 100
3/8	86	76 – 90
#4	59	44 – 74
#8	45	28 – 58
#50	16	5 – 21
#200	7.8	4 – 10

1.2. Preparation of Asphalt mixture

The wet mixing technique was adopted. Crumb rubber (CR) was added in specific quantities to asphalt, then mixed at a temperature that did not exceed 180°C for one hour using a 5000-rpm high-shear mixer. As Figure 2 illustrates, wet process modification. RAP was preheated for two hr. at the mixing temperature. The Marshall mix design method was utilized to prepare asphalt mixture specimens containing 10% of RAP with different CR dosages (2%, 4%, 6%, and 8%) by the binder weight. The aggregate blend gradation used in this investigation is presented in Table 4. Then, the mixed material samples were subjected to testing. Marshall samples have the optimal asphalt content of 5.0% for all crumb rubber content mixtures.

Table 4.
Blend of aggregate gradation.

Sieve size,	¾	½	3/8	#4	#8	#50	#200
Gradation of passing percentages	100	95	83	59	43	14	7

Figure 2.
Wet process modification of modified asphalt with crumb rubber.

1.3. Experimental Results and Discussions

The crumb rubber substantially impacts bitumen's elastic properties and stiffness, depending on the results obtained. Table 5 displays the original and rubberized bitumen's physical properties. Increasing the content of crumb rubber resulted in a decrease in the penetration of the studied specimens. This is due to the asphalt binder's interaction with the crumb rubber (CR). Additionally, the particles of crumb rubber (CR) adsorb the maltene during the blending process, which increases the asphaltene component on bitumen and then swelling.

Additionally, the stiffness of crumb rubber particles exceeds that of bitumen. Therefore, the stiffness of the rubber increases as the content of crumb rubber (CR) rises. It is deduced that the viscosity, softening point, and penetration index of rubberized asphalt increase as the rubber content increases. This is because of the absorption of the light, oily bitumen components during the interaction process

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by the crumb rubber. This suggests that rubberized bitumen would be more resistant to rutting and less sensitive to high-temperature changes.

Table 5.
Influence of crumb rubber percent on the physical characteristics of asphalt binder.

Property	Test results of CR binder				
	0%	2%	4%	6%	8%
Penetration	58	54	48	45	40
Penetration index	- 0.859	- 0.536	0.308	0.766	1.060
Ductility, cm	>100	>100	>100	>100	>100
Viscosity @135 °C, Pa.s.	370	410	480	525	540
Softening point, °C	50	52	57	60	63

Figure 3 depicts the results of the Marshall test for mixtures containing several percentages of modified binders with crumb rubber and 10% of RAP. It is evident from these results that crumb rubber has a significantly positive impact on mixes on the mechanical properties, including enhancement of the Marshall Stability of asphalt mixtures by the crumb rubber due to increased hardness and reduced sensitivity to high temperatures. These results were caused during the mixing process by the light asphalt fractions (maltenes fractions) absorption using relatively low proportions of rubber crumbs; the particles of rubber serve as a reinforcement-agent, increasing the asphalt mixture's adhesion and cohesion, thereby enhancing its load-carrying capacity. This increase in Marshall stability results from the binder's improved properties. The incorporation of RAP with the addition of crumb rubber in asphalt mixtures can also influence the result of the Marshall flow.

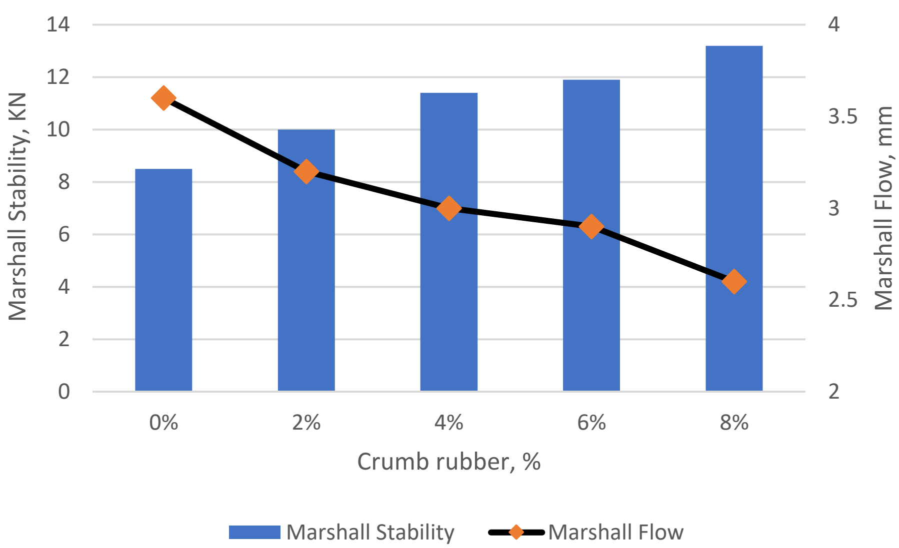

Figure 3.
Impact of crumb rubber on Marshall stability and flow.

Outcomes for the original and rubberized asphalt mixtures with the indirect tensile strengths (ITS) are presented in Figure 4. There is a considerably improves in the value of (ITS) due to incorporating crumb rubber powder and RAP. Indicates that rubberized asphalt samples exhibit superior TSR values compared to original asphalt mixtures. In Figure 5, TSR rises with an increase in CR content, indicating that the rubberized asphalt mixtures exhibit reduced vulnerability to moisture damage. The bitumen adhesion may be attributed the reason for this due to chemical modification, resulting in enhanced binder absorption capacity. Furthermore, crumb rubber particles possess hydrophobic characteristics, indicating their ability to prevent water. When incorporated into asphalt, they create a surrounded in the asphalt binder that diminishes water to penetrate.

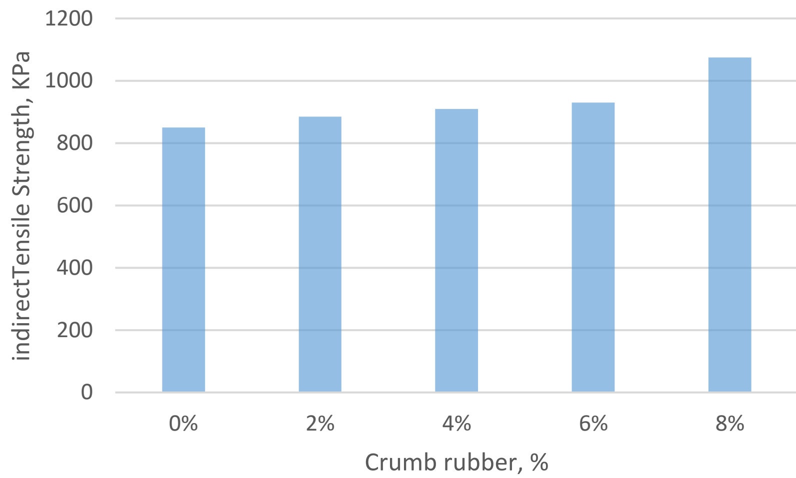

Figure 4.
Impact of crumb rubber on indirect tensile strength.

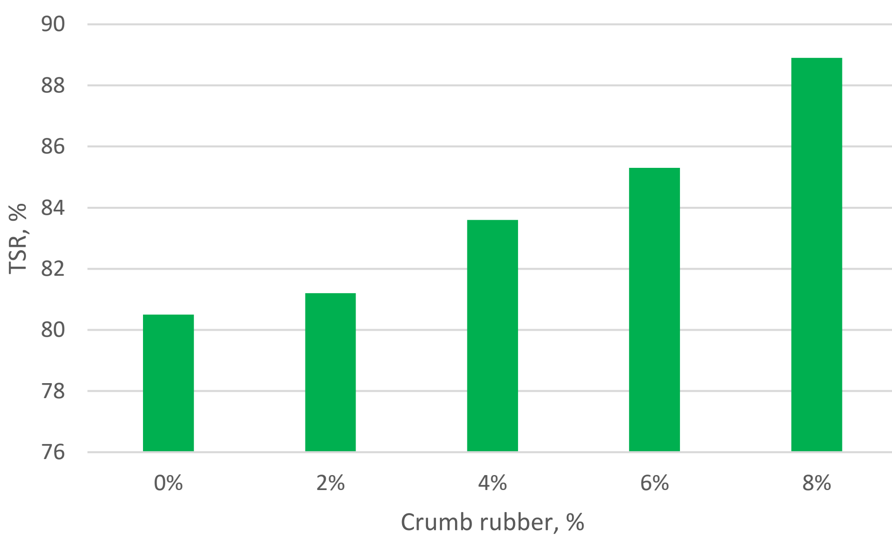

Figure 5.
Effect of crumb rubber addition on TSR.

The permeant deformation resistance of asphalt mixtures' impact with crumb rubber powder dosage is illustrated in Figure 6. Rubberized asphalt specimens exhibit superior rutting resistance than conventional mixtures. Moreover, increasing crumb rubber percentages caused the rutting resistance to increase. It is also observed that 8 percent of crumb rubber asphalt samples exhibited higher resistance to permeant deformation than others. The properties of the crumb rubber particles due to a higher degree of elasticity than conventional materials improve pavement elasticity, which can absorb and dissipate stress; this may be attributed to reducing the magnitude of permanent deformation of the modified binder at high temperatures.

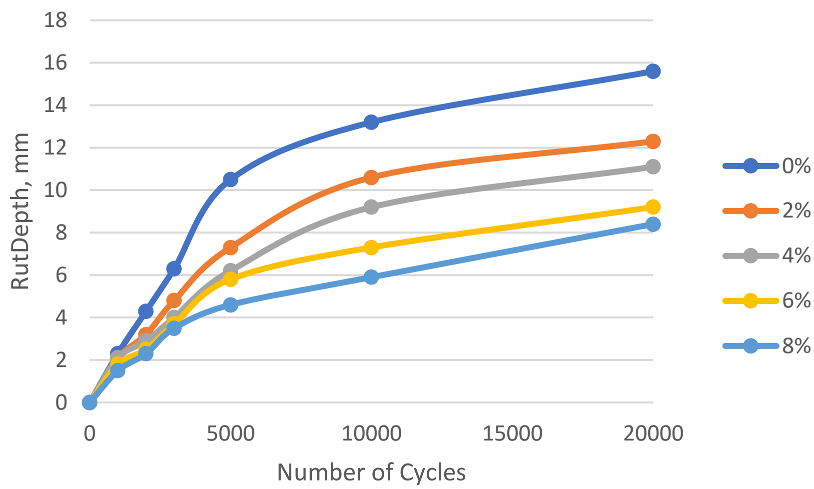

Figure 6.
Crumb rubber addition impact on rut depth.

2. Conclusions

This investigation demonstrates the benefit of crumb rubber utilization incorporate RAP asphalt mixtures on mechanical and durability properties. Furthermore, the potential enhancement of asphalt binder's properties. The characteristics of the asphalt binder, the dimensions and composition of the rubber particles, and mixing and compaction conditions affect the performance of crumb rubber.

One of the key practical benefits of using crumb rubber in RAP asphalt mixtures is its ability to enhance flexibility. This flexibility is crucial in enduring heavy traffic loads and minimizing the formation of cracks in the mixtures, a factor that is of particular interest to civil engineers and asphalt industry professionals.

Incorporating crumb rubber results in a more elastic and flexible material, a key finding that underscores the technical benefits of using crumb rubber in asphalt mixtures and enhancing the rubberized asphalt binder properties.

The study outcomes for Marshall, wheel track, and TSR tests indicated that the 8 % addition of crumb rubber increased Marshall stability to 13.2 (KN), TSR to 88.9%, and rut depth to 8.4 mm.

Utilizing recycled materials provides environmental benefits. Modified asphalt mixtures with crumb rubber contribute to conserving natural resources and reducing overall waste.

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