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Incorporating Recycled Crumb Rubber into Asphalt: A Comprehensive Review

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ABSTRACT

Using asphalt mixtures with added materials became a significant field for enhancing asphalt properties. Crumb rubber or recycled tire rubber is one of these materials that gained great attention because it provides asphalt mixtures with enhanced properties and with the privilege of being economically and environmentally efficient where it reduces the waste tires from being disposed to nature. This study explores the latest articles in this field with a focus on different methods used to incorporate crumb rubber (CR) into the asphalt matrix. It has been noticed that most articles focus on the wet process for incorporating CR into asphalt. This method is known for its efficiency, but it consumes less CR as compared to the dry process. The dry process deals with CR as a substitute rather than an additive, but it is used less around the world in enhancing asphalt properties where it has less effect on asphalt characteristics development. The third method (terminal) is a mix between the mentioned methods and comprises the prospectives of both methods. The need for this research is underscored by the growing environmental and economic challenges associated with waste tire disposal and the continual degradation of road infrastructure. This study contributes to developing more sustainable, durable, and cost-effective road paving solutions by exploring the efficacy and methods of crumb rubber integration into asphalt.

Keywords: Crumb rubber, Sustainability, Wet process, Dry process

1. INTRODUCTION

Asphalt concrete mixtures are integral to national highways and are crucial in sustaining commerce and personal mobility. Despite their importance, asphalt pavements are increasingly plagued by reduced longevity and various failures. These issues may be related to many factors such as changes in crude oil and refining processes, improper mixture design, increasing pressure from tires, characteristics development, and additive misuse. Accurately, the dropouts in asphalt make can be displayed in three shapes: rutting, which is

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caused by high temperatures and heavy truck movement; fatigue cracking, which is caused by repetitive loading; and low-temperature cracking, which is caused by thermal stresses **(Asam, 2001)**.

In Iraq, rapid development and a construction boom have led to escalated traffic volumes, often surpassing designed load capacities. Coupled with the region's high temperatures, these factors significantly contribute to premature pavement distress, particularly rutting and moisture damage. Baghdad, where roads and their maintenance hold great importance, exemplifies the need for resilient infrastructure. One of the 21st century's pressing waste management challenges is tire disposal after their useful lives. Due to their flammability and chemical composition, these non-biodegradable items are significant sources of dangerous vapors and toxins seeping into the ground and water **(Albayati, 2012)**.

However, the value of the rubber content in these tires should not be overlooked **(Karakurt, 2015; Markl and Lackner, 2020)**. Utilizing crumb rubber (CR) as a pavement additive that improves performance offers a viable recycling and reuse strategy **(Bressi et al., 2019; Brasileiro et al., 2019)**. Furthermore, the solar radiation-induced degradation of stockpiled tires poses a long-term threat to soil and groundwater. When burned, tires generate thick, black smoke, spread heat rapidly, and leave behind soil-contaminating oily residue. Incorporating scrap tire rubber in concrete, alongside fine and coarse aggregates, has been explored to mitigate waste and yield environmental and health benefits **(Brito and Saikia, 2012; Kocsis et al., 2013; Miranda, 2018)**. When waste tires are disposed of or incorrectly recycled, there can be severe health and environmental consequences. Consequently, their recycling into civil engineering applications, notably asphalt paving mixtures and Portland cement concrete, has garnered increasing interest. Integrating crumb rubber in asphalt mixtures has proven successful in enhancing compatibility with rubber particles and asphalt binder and improving mixture properties **(Wulandari and Tjandra, 2017)**.

Many research articles have explored the effects of substituting crumb rubber instead of regular aggregates on concrete and asphalt's resulting performance **(Zhang et al., 2022; Mohammed et al., 2023)**. **(Deshmukh et al. 2017)** have noticed the antioxidant properties of carbon, which is one of the significant constituents of CR, leading to more ageing resistance of the produced asphalts. Also, many studies explored the effect of crumb rubber on asphalt properties, such as marshal stability, moisture resistance, and mechanical properties **(Shu and Huang, 2014; Al-Mosawi, 2023)**. In addition to the properties mentioned above, (**Saad et al., 2019; Ahmad, 2015)** evaluated the stability, resistance to rutting and moisture damage of such mixes. (**Tahami et al., 2019)** explored the effect of CR on asphalt rutting properties.

The purpose of this study is to discover the environmental benefits and efficiency of using crumb rubber in asphalt mixtures with an emphasis on sustainable solutions in the asphalt pavement industry by using recycled materials, which enables us to enhance asphalt properties on one side and save nature from wasted tires in the other.

2. ASPHALT CONCRETE

Asphalt or bitumen is a hydrocarbon produced after refining crude oil and removing lighter components **(Zheng et al., 2021)**. It consists of 4 major components: Asphaltene, colloid, aromatic, and saturated ingredients, and is usually regarded as the same colloidal system **(Padmarekha and Krishnan, 2011; Zuo et al., 2019).** Road construction, an essential part of transportation infrastructure, requires a careful balance between safety and cost-

effectiveness. Engineers must consider the environmental impact, traffic demands, and properties of asphalt mixtures in their designs **(Peralta, 2009; Mashaan, 2012).**
In asphalt concrete (AC), asphalt cement is used as a binder, serving several critical roles: it holds the aggregates together and acts as a waterproof sealant. However, asphalt cement can change over time, leading to fatigue and cracking in the pavement **(Mahrez, 2008; Peralta et al., 2010).** Such pavement distresses, including rutting and fatigue cracking, often originate from issues with the asphalt cement and the mixture. Traditional asphalt's dynamic characteristics and long-term durability are insufficient to withstand these loads, prompting researchers to investigate alternatives such as crumb rubber-modified asphalt **(Mashaan, 2014; Wang et al., 2018)**.
The performance of bituminous surfacing is significantly influenced by two types of factors: vehicular and thermal. Vehicle loads can cause distress at extreme pavement temperatures **(Sarsam and Hasan, 2017)**. When temperatures are high, asphalt cement may become too fluid, failing to resist the tearing operation of vehicle tires. In contrast, it might become brittle at lower temperatures, leading to fractures under vehicle stress. The "Normal Stresses" theory explains this behavior. The Wiesenberger effect applies to viscoelastic materials such as asphalt cement/scrap rubber mixes. This theory focuses on normal stress differences, which are forces that arise vertically in the direction of the shear. **(Oliver et al., 1981; Lin et al., 2017)**.

3. KINDS OF ASPHALT CONCRETE MIXTURES

In the field of roads, different kinds of asphalt mixtures are used to fulfill the needs and circumstances of every environment. The hot mix asphalt process is famous for its durability. Also, there are other processes, such as warm mix and cold mix, which have their application in specific criteria. As specified by **(Nikolaides, 2015; Mohammed et al., 2024),** all these mixed processes have their characteristics and applications in roads.

3.1 Hot Mix Asphalt

In the road building industry, hot mix asphalt has an important role, as all materials are mixed with hot asphalt at 140-160 degrees. The temperatures are selected depending on asphalt viscosity and grade, which allows for the perfect wetting of constituents by the asphalt. In the last years, crumb rubber was introduced to the hot mix method to improve further the properties of the resulting asphalt, which provides more durability and resistance to ageing and cracking in addition to the advantage of getting rid of wasted tires **(Nikolaides, 2015; Albayati, 2017)**.

3.2 Cold Mix Asphalt

This method is considered a highly efficient mix in asphalt production where it is prepared at the current temperature without the need for more energy. This type is produced by asphalt emulsion by mixing with water, which reduces its viscosity and mixes it with aggregates at 25 °C for two minutes. In this period, the water vapors from the emulsion of asphalt let it retain its characteristics. This method is practical for maintaining roads **(Mahdi and Sarsam, 2019)**.

3.3 Warm Asphalt Mixture

This method contributes to the development of road making, comprising the advantages of both cold and hot processes. It is famous for producing a mixture at 110-135 degrees for mixing and 100-115 degrees for compression. The low temperatures lead to a decrease in the viscosity of the mixture. This technique provides durability and energy efficiency **(Sarsam, 2019; Nikolaides, 2015)**.

4. CRUMB RUBBER

Initiated in the 1960s, its integration into asphalt was driven by the rubber's inherent elasticity, enhancing both skid resistance and durability in asphalt formulations **(Cong et al., 2013; Wang et al., 2013)**. This benefited pavement quality and provided a sustainable avenue for recycling used tires. Research indicates that crumb rubber is commonly incorporated into asphalt using three methods **(Hassan et al., 2014)**. **Table 1** shows the chemical composition of crumb rubber. Predominantly consisting of vulcanized rubber and various reinforcing agents, tires, as depicted in **Fig. 1**, primarily comprise natural rubber, contributing to their robustness and longevity **(Asaro et al., 2018; Akca et al., 2018)**. However, natural rubber's temperature-sensitive nature makes it prone to stickiness and reduced elasticity, leading to deformation when heated and brittleness upon cooling **(Karakurt, 2015)**.

Table 1. Chemical composition and characteristics of the used CR (by the manufacturer).

Properties	Description or value
Source	Scrap truck Tires
Color	Black
Morphology	porous
Specific gravity (g/cm^3)	1.15
Decomposition temperature	~ 200
Total rubber(natural and synthetic)	55
Carbon black%	30
Zinc oxide	1.5
Sulfur	1
Benzene extraction	5.5
Ash content	7

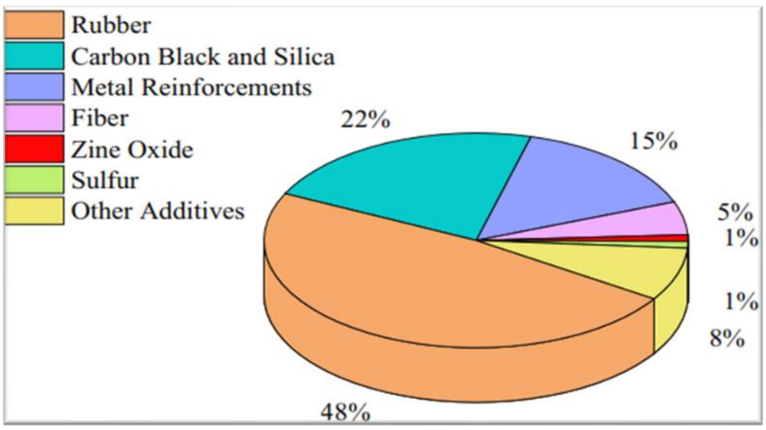

Figure 1. A typical composition of a vehicle tire **(Asaro et al., 2018; Akca et al., 2018).**

In road construction, Crumb Rubber (CR) is increasingly seen as a solution for waste tire management **(Mashaan et al., 2014; Lo Presti, 2013)**. CR is integrated into the pavement in particle size between(4.75 mm -sieve No.4) to (0.075 mm sieve No.200) by mechanically pulverizing shredded tires via ambient and cryogenic methods under various conditions **(Blumenthal, 1996; Hassan et al., 2014)**.

As **Fig. 2** illustrates, the surface texture of CR, as observed in an SEM test, varies depending on the grinding method **(Hassan et al., 2014)**. Ambiently ground CR particles are irregular and rough, possessing a greater surface area. Their porous surface can absorb oils and resins in the asphalt binder, enhancing binding efficiency **(Sienkiewicz et al., 2012; Garcia et al., 2015; Xiang et al., 2018)**. However, these particles are susceptible to ageing due to their texture and porosity, especially under heat and oxygen exposure. Upon immersion in asphalt binder, CR particles swell, filling their pores with lighter components, thereby forming a denser compound. Creating crumb rubber involves shredding tires, which are a mix of natural and synthetic rubber and carbon black, into smaller particles, simultaneously removing metal and fabric reinforcements **(Nejad et al., 2012; Alsheyab et al., 2023)**. This process results in a material that cannot be re-softened upon reheating. Factors like the rubber's type, amount, shape, and gradation significantly influence the behavior of rubber-modified asphalt mixtures **(Moreno et al., 2012)**. The dimensions and texture of the rubber particles are tailored according to specific application requirements to ensure optimal performance.

Rubber particles exhibiting inconsistent shapes and a large surface area react extra effectively with asphalt at high temperatures, resulting in a superior modified binder. Conversely, cubic-shaped particles with lower surface areas, resembling aggregates, are preferred in the dry process for their ease of integration as elastic aggregates **(Zheng et al., 2021)**. Scrap tires are processed primarily through ambient granulating (cracker-mill process) and cryogenic grinding. Both techniques reduce tire crumb particle size and separate rubber from steel and fibers. Ambient granulating, involving screeners, granulators, conveyors system, and magnets for steel removal, is the prevalent method, producing irregular, sponge-like particles varying from 0.425 mm to 4.75 mm in size, as shown in **Fig. 2**.

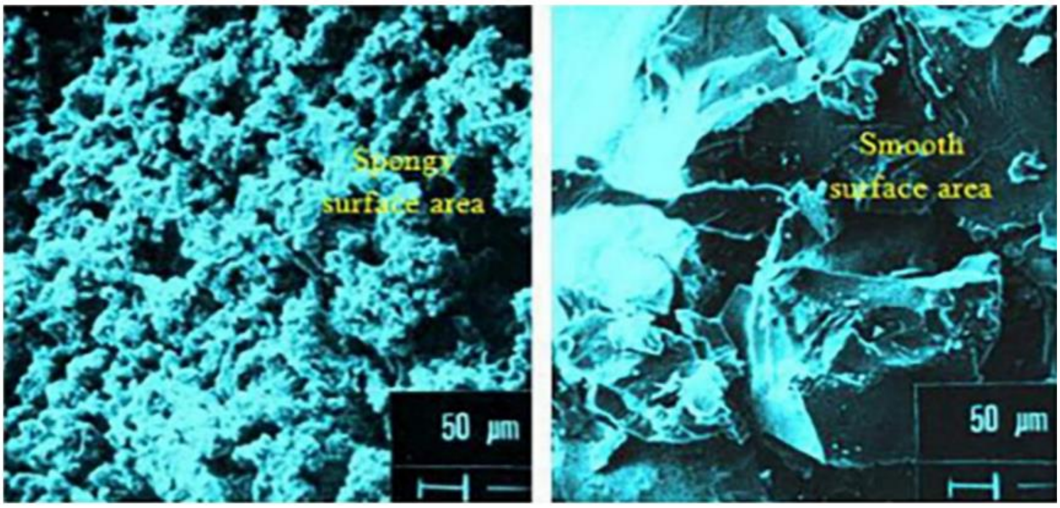

Figure 2. The scanning electron microscope (SEM) image shows crumb rubber on the left and ambient granulating synthetic tyre rubber on the right. Artificial tyre rubber that has been crushed using cryogenic methods**(Hassan et al., 2014).**

Cryogenic grinding, performed at temperatures between -87 to -198°C using liquid nitrogen, yields a brittle, glasslike rubber with lower surface area and elastic recovery compared to ambient granulated rubber **(Hernandez et al., 2009).**
The large surface area and non-uniform shape of ambient granulated rubber result in increased binder viscosity compared to cryogenically processed rubber, facilitating a quicker reaction with bitumen **(Huang et al., 2002; Thodesen et al., 2009)**.

4.1 Environmental Problems Related to Scrap Tires

The increasing rate of population and industrialization causes waste products at undesirable levels. One of these waste products is scrap tires (also called "end-of-life tires" (ELT)) **(Pereira et al., 2008; Presti, 2013).** Every year, approximately 17 million scrap tires are generated across the world and the annual growth rate of this number is estimated at 2%. The amount of scrap tires produced in the U.S. was 4,658,302 tons in 2019. Scrap tires are seen as one of the most concerning waste products as they are manufactured in large volumes and don't decompose easily **(Presti, 2013)**. They are either stockpiled/landfilled or utilized as fuel, new recycled products, and recycled tire production. Improper management of disposed scrap tires may pose environmental and health risks such as fire hazards and a place to breed for rodents and pests like mosquitos **(Presti, 2013)**.

4.2 Utilizations of the Scrap Tire

One of these uses is to use them as a fuel source since they provide energy at the level of good quality coalsthe Another approach is to process scrap tires chemically, i.e., thermolysis, pyrolysis, and gasification. Scrap tires are utilized in ground form after the steel and fabric components of these tires are separated. In the civil engineering area, crumb rubber (ground tire rubber) is used for different purposes such as rubberized asphalt pavements, flooring for playgrounds and stadiums, shock-absorbing mats, paving blocks, roofing material, and more **(Paje et al., 2013).** where The current applications of recycling waste tires in civil engineering practices mainly are as follows:

1. Used as modifiers to asphalt paving mixtures
2. Used as an additive to Portland cement concrete
3. Used as lightweight fillers
4. Used in whole tires as crash barriers, bumpers, and artificial reefs, etc.

5. CRUMB RUBBER APPLICATION METHODS

Crumb rubber is incorporated into asphalt by using three methods, which are depicted in the following sections:

5.1 Wet Process

The crumb rubber is mixed with asphalt, as depicted in **Fig. 3.** This process proved its efficiency in enhancing the overall performance of asphalt roads by increasing the age, lowering the noise, and improving the temperature resistance in addition to being an environmentally friendly process **(Presti et al., 2013; Singh et al., 2019; Wang et al., 2019)**. Yet, there is the problem of crumb rubber segregation from the asphalt **(Sienkiewicz**

et al., 2017; Hallmark-Haack et al., 2019), and this separation of CR from its binder is due to the high rate of settling of CR and incompatibility. The difference in densities between the binder and the CR particles is another reason, in addition to the swelling problem of the CR particles **(Wenhua Zheng et al., 2021)**.

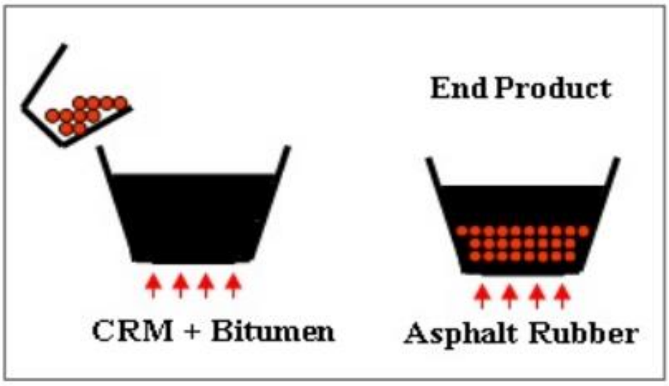

Figure 3. The wet process **(Hassan et al.,2014)**

5.2 Dry Process

During the dry process, a fraction of the aggregate in the mixture is substituted with large rubber particles. As seen in **Fig. 4**, the rubber predominantly functions as an elastic aggregate in the mixture. This technique leads to the creation of what is known as a rubber-modified asphalt mixture, or 'CRM mixture', produced through the dry process. Historically, CRM mixtures were formulated without specific guidelines or formal standards. However, more recently, there has been a shift towards more structured asphalt mixture design approaches **(Hassan et al., 2014)**.

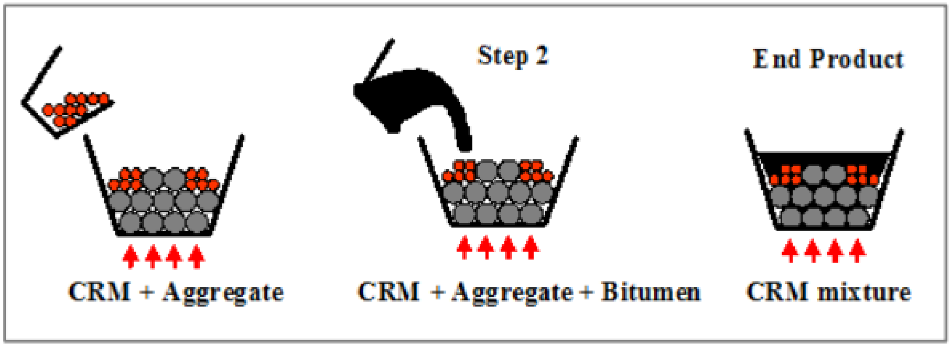

Figure 4. Dry process **(Hassan et al., 2014).**

5.3 Terminal Blend Process

The final mixing process is the third primary method for mixing rubber crumbs in asphalt mixtures, as fine rubber particles are mixed with the asphalt binder, and through this, we obtain a homogeneous and stable mixture. After this, we work to introduce additional rubber crumbs into the mixture as fine or coarse aggregate. This process ensures a comprehensive and even distribution of the rubber particles within the asphalt, enhancing the binder's performance and effectiveness. This method is distinguished by its ability to produce rubber asphalt that is more malleable and easier to handle than other methods, making it suitable for wide paving applications. This method often produces a mixture with improved resistance to aging and enhanced durability. This contributes to extending the life of road surfaces, as the fine particle size of the crumb rubber used in the final mixing process allows for seamless integration into the asphalt matrix, ensuring consistency in the final product (**Ahmad, 2015).**

6. CHARACTERISTICS OF RUBBERIZED ASPHALT

Sweden was the origin of dry mix rubberized asphalt, which was developed to improve the skid and durability of roads. In 1978, the USA patented a method for incorporating coarse rubber particles into asphalt. This method employs coarse rubber particles to serve as elastic aggregates, thereby increasing the flexibility of the mixture when subjected to load. It has been reported that the bitumen undergoes a partial reaction with the finer rubber particles, resulting in an increase in viscosity and enhanced flexibility of the binder at low temperatures while maintaining its high rigidity at high temperatures **(Thodesen et al., 2009; Cong et al., 2013; Presti et al., 2013)**. Typically, 1% to 3% coarse rubber by weight of the total mixture is added, with particle sizes between 2.0 mm and 6.3 mm **(Mohammed et al., 2012;Issa et al., 2013)**. The aim is to substitute a portion of aggregates with rubber, providing elastic properties. By limiting the reaction time between bitumen and rubber particles and using coarse granulated rubber, the rubber retains its shape and rigidity. In gap-graded mixtures, rubber particles fill the voids between aggregates, while in densely graded mixtures, a coarser aggregate gradation is needed for rubber modification. The initial use of the dry mixing method was to improve pavement performance under snow and ice conditions. **(Esch et al.,1982)** reported higher skid resistance and reduced vehicular stopping distance on icy pavements using the PlusRide mixture. Additionally, according to a 1992 Federal Highway Administration report, the Cold Regions Research Engineering Laboratory investigated dry process formulations for ice debonding on pavements, noting increased ice cracking with higher coarse rubber content. However, these tests were limited to laboratory settings.

The interaction between crumb rubber (CR) and asphalt binder significantly impacts the rubberized asphalt binder's rheological properties and storage stability. Studies by **(Liu et al.,2019; Ghavibazoo et al.,2013)** have shown that CR does not affect the asphalt binder's functional groups and molecular structures, indicating a predominantly physical modification process. This interaction depends on variables like the type, percentage, size, and grade of CR and asphalt binder, and interaction parameters such as combining technique, heat degree, and time. This method involves swelling the crumb rubber **(Jamrah et al., 2019).** The interaction of rubber and CR which involoves difusion of lighter fractions of asphlat into CR eventually leading to sewlling. This process is depicted in **Figs. 5** and **6 (Fini et al. 2017; Wang et al. 2019; Hassan et al., 2014)**. The interfacial zone between CR and asphalt is transformed into a gel-like structure, increasing the viscosity and affecting the workability **(Thodesen et al., 2009; Shen et al., 2009)**.

Although it has poor workability and separation, CR-modified asphalt showed many privileges like improving crack resistance and performance in low temperatures, stress resistance and noise reduction in addition to lowering the costs of production **(Zheng et al., 2021; Wang et al., 2021)**

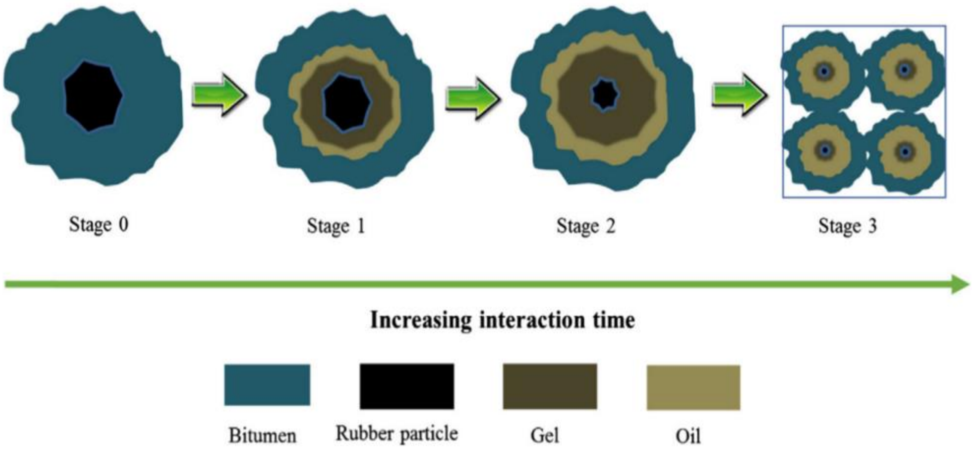

Figure 5. Schematic representation of the asphalt binder-CR interaction process **(Wang et al., 2019)**

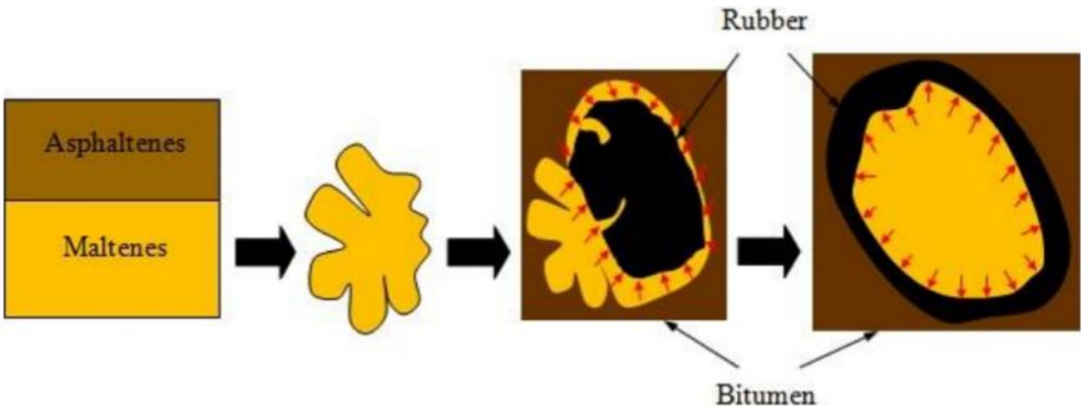

Figure 6. Diagram illustrating the diffusion of maltenes into crumb rubber **(Hassan et al., 2014)**

This vast exploration of the characteristics of CR-modified asphalt and the variations in methods and dosages of CR proves the capability of using CR in enhancing asphalt properties, as shown in **Table 2,** which summarizes different approaches to using CR in asphalt modification.

Table 2. Summary of previous studies

Reference	CR addition method	Investigated dosages	Main conclusions
(Khedaywi et al., 1993)	Wet	5–15% (by weight of asphalt cement)	Demonstrated significant improvement in asphalt concrete's volumetric properties and creep resistance, suggesting CR's pivotal role in roadway service life longevity.
(Cao, 2007)	Dry	1%, 2%, 3% (by weight of total mix)	Showed significant mitigation of deformation and cracking, highlighting CR's effectiveness in enhancing high- and low temperature performance.
(Moreno et al., 2012)	Dry	0%, 0.5%, 1%, 1.5% (by weight of total mix)	Found that 1% CR addition optimally counteracts plastic deformations, offering the best resistance against rutting.

(Cetin, 2013)	Dry	10%, 15%, 20% (by weight of total mix)	Optimal at 10% CR, #20~#200-sized particles decreased air voids and permeability but increased Cantabro abrasion loss, impacting porous asphalt performance negatively with larger CR sizes and contents
(Hassan et al., 2013)	Dry	1 to 3% (by weight of total mix)	Illustrated that CR addition affects mix design and rutting resistance, emphasizing CR's role in optimizing bitumen content and enhancing mixture resilience.
(Ahmad, 2015)	Terminal blend method	4.5%, 5%, 5.5%, 6%, 6.5%, 7% (by weight of asphalt cement)	Highlighted challenges due to segregation in the dry process while pinpointing specific CR percentages in the wet process as optimal
(Issa, 2016)	Wet	5%, 10%, 20% (by weight of total mix)	Emphasized that 10% CR addition significantly enhances the rubber-asphalt mixture's properties, offering an optimal balance for pavement performance.
(Wulandari and Tjandra, 2017)	Wet	1%, 2% (by weight of asphalt cement)	Advocated for CR as a beneficial additive, noting improvements in strength, quality, stability, and flow, indicative of a more robust pavement structure.
(Al-Azawee and Qasim, 2018)	Wet	0, 5, 10, 15% (by weight of asphalt cement)	Observed that 10% CRM is the optimum addition content, enhancing volumetric properties and Marshall stability crucial for the mixture's load-bearing capacity.
(Tefera et al., 2018)	Terminal blend method	0%, 5%, 10%, 15%, 20% (by weight of total mix)	Revealed that 15% CR content notably improves stability and performance, indicating higher CR concentrations dramatically augment pavement strength.
(Tahami et al., 2019)	Dry	20%, 40%, 60% (by weight of total mix)	Suggested CRP acts as a variable filler that can diminish or enhance moisture damage resistance, indicating the importance of CRP content and processing.
(Eltwati et al., 2019)	Dry	0.5%, 1.0%, 1.5%, 2% (by weight of total mix)	Concluded that a 2% CR content yields the highest resistance to rutting, pointing towards CR's role in enhancing resilience under repetitive loading.
(Bakheit and Xiaoming, 2019)	Terminal blend method	6%, 12%, 18%, 24% (by weight of total mix)	Found that the complex method of CR addition elevates Marshall's stability beyond traditional methods, proposing a novel approach for leveraging CR benefits.
(Hassan et al., 2019)	Dry	0, 1.5, 2.5% (by weight of total mix)	Pointed out that fine CR notably improves asphalt mixture properties, suggesting particle size is critical in determining CR's effectiveness.
(Salama et al., 2020)	Wet	16, 20, 24, 28% (by weight of asphalt cement)	The 20-24% CR range was identified as yielding favorable outcomes against rutting and moisture damage, advocating for this concentration as optimal.
(Fayyadh and Al-	Dry	1%, 1.5%, 2% (by weight of total mix)	Noted that 1% CR content minimizes moisture susceptibility, highlighting CR's nuanced impact on asphalt mixtures' moisture sensitivity.

Mosawe, 2022)			
(Tan et al., 2022)	Dry	0%, 1%, 2%, 4% (by weight of total mix)	Determined that 1% CR content satisfies international standards for modified asphalt, suggesting minimal CR incorporation significantly enhances pavement properties.
(Khadim and Al-Mosawe, 2023)	Wet	0, 2, 4, 6, 8% (by weight of asphalt cement)	The importance of selecting appropriate CR sources and sizes for improved asphalt mixture performance is highlighted, especially in enhancing Marshall stability.
(Al-Soudany et al., 2023)	Wet	6, 9, 12, 15% (by weight of asphalt cement)	Indicated that a 9% CR addition notably increases Marshall Stability, underscoring CR's potential to significantly bolster pavement robustness.
(Šernas et al., 2023)	Dry	0.5% to 3.0% (by weight of total mix)	Demonstrated that up to 3.0% CR addition positively impacts resistance to low-temperature cracking, offering a compelling argument for CR incorporation.

7. PROS AND CONS OF CR MODIFIED ASPHALT CONCRETE

Using asphalt mix modified with CR was of considerable interest due to its capability to enhance the performance of asphalt and its sustainability. There are two main reasons for using CR in asphalt: First, to improve mechanical properties and increase the ageing resistance and durability of the asphalt mixture. Second, to participate in protecting nature from waste materials. In **Table 3**, there is a comparison to show the effects of adding CR to asphalt by showing the benefits and drawbacks.

Table 3. Pros and cons of CR incorporation in asphalt.

No.	Reference	Pros	Cons
1	**(Irfan et al., 2018)**	Enhanced Performance Metrics: CR-modified asphalt improves key performance metrics like rutting resistance and elasticity, essential for enduring heavy traffic loads.	Potential Moisture Damage: The interaction between CR and asphalt binder might increase water sensitivity, risking stripping and adhesion loss in wet conditions.
2	**(Wang et al., 2017)**	Improved Low-Temperature Behavior: Better performance in low temperatures reduces the likelihood of thermal cracking, which is beneficial in colder climates	Compaction and Workability Issues: Increased viscosity from CR can complicate workability and compaction, often requiring higher temperatures and leading to higher energy consumption and aging issues.
3	**(Nunn et al., 2001)**	Increased Fatigue Life: Extended fatigue life means the pavement can withstand stresses from cyclic traffic loads for more extended, reducing maintenance needs	Environmental and Health Concerns: Production may release unpleasant odors and smoke, posing health risks to workers and potential environmental pollution.
4	**(Biligiri and Way, 2014)**	Noise Reduction: CR-modified asphalt has noise-dampening properties, contributing to quieter road environments, which is particularly valuable in urban areas	Cost and Resource Implications: Initial costs and resources for producing CR-modified asphalt can be higher than traditional methods, including the need for specialized equipment.

8. CONCLUSIONS

Modifying asphalt by CR is a complicated process exploring the many side effects of asphalt modification. This study discovers the detailed differences in CR interaction with asphalt and methods of incorporation in improving the performance of asphalt. The main points extracted from the most important results and the challenges and advantages in the field of asphalt modification are:

1. Rubber particles are characterized by their inconsistent forms, and large surface areas react extra effectively with bitumen at elevated temperatures, creating an altered adhesion that enhances the asphalt's overall performance.
2. Cubical-shaped rubber particles, typically with lower surface areas, are well-suited for Intended for utilization in the dry process as flexible aggregates, easily integrating into the aggregate mix and adding flexibility to the asphalt.
3. The manufacturing method of crumb rubber, mainly ambient versus cryogenic grinding, significantly influences the extent of property enhancement in asphalt, with ambient ground rubber reacting faster with bitumen than cryogenically ground rubber.
4. The modification process of asphalt binder with CR is predominantly a physical reaction. However, it varies based on factors such as type, percentage, size, grade of CR and asphalt binder, and interaction conditions like temperature and mixing duration.Typical CR dosages for the dry addition method range from 1% to 3% by total aggregate weight. For the wet addition method, CR dosages typically as the best percentages range from 15% to 22% by the total weight of the binder. This method is effective for significant modifications in the properties of the binder itself These dosages can vary depending on specific requirements and materials used,
5. CR-modified asphalt demonstrates enhanced resistance to common distresses like rutting and cracking, attributed to the improved elasticity and stiffness provided by the rubber particles.
6. The presence of CR in asphalt mixtures can influence moisture susceptibility, with potential impacts on the water sensitivity of the mix, necessitating careful design to mitigate risks of moisture damage and stripping.
7. The asphalt pavement industry continuously evolves, with advancements in mixture formulations and application techniques. This includes new methods to optimize the use of CR in asphalt mixtures, balancing performance improvements with environmental and practical considerations.

Credit Authorship Contribution Statement

Safa Ihsan Oleiwi: Writing – reviewing &editing.
Dr. Amjad Hamad Khalil: Supervision, reviewing, evaluation & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

Ahmad, O.A., 2015. Using crumb rubber (CR) of the scrap tire in hot mix asphalt design. Department of Civil Engineering Faculty of Engineering Technology, Zarqa University, Zarqa, Jordan, https://doi.org/10.3844/ajassp.2017.274.285.

Akca, E., Gursel, A., and Sen, N., 2018. A review on devulcanization of waste tire rubber. *Periodicals of engineering and natural sciences*, 6(1), pp. 154-160, https://doi.org/10.21533/pen.v6i1.167.

Al-Azawee, E.T., and Qasim, Z.I., 2018. The influence of crumb rubber modifier (CRM) on the properties of asphalt concrete mixtures. *International Journal Civil Engineering Technology*, 9(10), pp. 201-212. http://iaeme.com/Home/issue/IJCIET?Volume=9&Issue=10.

Albayati, A.H., 2012. Mechanistic evaluation of lime-modified asphalt concrete mixtures. In 7th RILEM International Conference on Cracking in Pavements: Mechanisms, Modeling, Testing, Detection and Prevention Case Histories (pp. 921-940). Dordrecht: Springer Netherlands,. https://doi.org/10.1007/978-94-007-4566-7_89.

Albayati, A.H., 2017. Influence of temperature upon permanent deformation parameters of asphalt concrete mixes. *Journal of Engineering*, 23(7), pp. 14-32, https://doi.org/10.31026/j.eng.2017.07.02.

Al-Fayyadh, Z.T., and Al-Mosawe, H., 2022. The effect of short-term aging on warm mix asphalt moisture performance. *Civil Engineering Journal*, *8*(12), pp. 2789-2802, https://doi.org/10.28991/CEJ-2022-08-12-09.

Al-Mosawe, H.M., 2023. Enhancing Asphalt Mixture Performance with Crumb Rubber: A Sustainable Solution for Improved Durability and Mechanical Properties. In E3S Web of Conferences (Vol. 427, p. 03017). EDP Sciences, https://doi.org/10.1051/e3sconf/202342703045.

Alsheyab, M. A., Khedaywi, T., and Ogiliat, O., 2023. Effect of waste Tire rubber on properties of asphalt cement and asphalt concrete mixtures: state of the art. *International Journal of Pavement Research and Technology*, pp. 1-12, https://doi.org/10.1007/s42947-023-00361-4.

Al-Soudany, K. Y., Mohammed, H. H., Hussein, L. Y., and Qasim, Z. I., 2023. Experimental study of the effect of crumb rubber on properties of asphalt mix by wet process. In *E3S Web of Conferences* (Vol. 427, p. 03034). EDP Sciences. https://doi.org/10.1051/e3sconf/202342703034.

Asam, 2001. Laboratory evaluation of the effect of Superpave gradations and polymer-modified asphalts on pavement performance (Doctoral dissertation, Ohio University).

Asaro, L., Gratton, M., Seghar, S., and Hocine, N. A., 2018. Recycling of rubber wastes by devulcanization. *Resources, Conservation and Recycling*, 133, pp. 250-262, https://doi.org/10.1016/j.resconrec.2018.02.016.

Bakheit, I., and Xiaoming, H., 2019. Modification of the dry method for mixing crumb rubber modifier with aggregate and asphalt based on the binder mix design. *Construction and Building Materials*, *220*, pp. 278-284, https://doi.org/10.1016/j.conbuildmat.2019.06.050.

Blumenthal, M. H., 1996. *Producing ground scrap tire rubber: a comparison between ambient and cryogenic technologies* (No. CONF-960345-). American Society of Mechanical Engineers, New York, NY (United States),

Brasileiro, L., Moreno-Navarro, F., Tauste-Martínez, R., Matos, J., and Rubio-Gámez, M.D.C., 2019. Reclaimed polymers as asphalt binder modifiers for more sustainable roads: A review. *Sustainability*, 11(3), P. 646. https://doi.org/10.3390/su11030646.

Bressi, S., Fiorentini, N., Huang, J., and Losa, M., 2019. Crumb rubber modifier in road asphalt pavements: State of the art and statistics. *Coatings*, 9(6), P. 384, https://doi.org/10.3390/coatings9060384.

Biligiri, K. P., and Way, G. B., 2014. Noise-damping characteristics of different pavement surface wearing courses. *Road Materials and Pavement Design*, *15*(4), pp. 925-941, https://doi.org/10.1080/14680629.2014.902768.

Cao, W., 2007. Study on properties of recycled tire rubber modified asphalt mixtures using dry process. *Construction and Building Materials*, 21(5), pp. 1011-1015, https://doi.org/10.1016/j.conbuildmat.2006.02.004.

Cetin, A., 2013. Effects of crumb rubber size and concentration on performance of porous asphalt mixtures. *International Journal of Polymer Science*, 2013, https://doi.org/10.1155/2013/789612.

Cong, P., Xun, P., Xing, M., and Chen, S., 2013. Investigation of asphalt binder containing various crumb rubbers and asphalts. *Construction and Building Materials*, 40, pp. 632-641, https://doi.org/10.1016/j.conbuildmat.2012.11.063.

Brito, J., and Saikia, N., 2012. Recycled aggregate in concrete: use of industrial, construction and demolition waste. *Springer Science & Business Media*.

Deshmukh, N.H., and Kshirsagar, D.Y., 2017. Utilization of rubber waste in construction of flexible pavement. *International Journal for Advance Research and Development*, 2(7), pp. 70-77, https://doi.org/10.4028/www.scientific.net/KEM.599.361.

Eltwati, A. S., Saad, I., and Elsaiti, A., 2019. The effect of crumb rubber on properties of asphalt mix by dry process. *The International Journal of Engineering and Information Technology* (Ijeit), 5(1).

Esch, D. C., 1982. Construction and benefits of rubber-modified asphalt pavements (No. AK-RD-82-17). Alaska. Deptartment of Transportation and Public Facilities.

Fini, E. H., Hosseinnezhad, S., Oldham, D., Mclaughlin, Z., Alavi, Z., and Harvey, J., 2019. Bio-modification of rubberised asphalt binder to enhance its performance. International Journal of Pavement Engineering, 20(10), pp. 1216-1225, https://doi.org/10.1080/10298436.2017.1398548.

Garcia, P. S., De Sousa, F. D. B., De Lima, J. A., Cruz, S. A., and Scuracchio, C. H., 2015. Devulcanization of ground tire rubber: Physical and chemical changes after different microwave exposure times. *Express Polymer Letters*, 9(11), https://doi.org/10.1038/s41598-020-73543-w.

Ghavibazoo, A., and Abdelrahman, M., 2013. Composition analysis of crumb rubber during interaction with asphalt and effect on properties of binder. *International Journal of Pavement Engineering*, 14(5), pp. 517-530, https://doi.org/10.1080/10298436.2012.721548

Hallmark-Haack, B. L., Hernandez, N. B., Williams, R. C., and Cochran, E. W., 2019. Ground tire rubber modification for improved asphalt storage stability. *Energy & Fuels*, 33(4), pp. 2659-2664, https://doi.org/10.1021/acs.energyfuels.8b03558.

Hassan, N. A., Almusawi, A. A. A., Mahmud, M. Z. H., Abdullah, N. A. M., Shukry, N. A. M., Mashros, N., ... and Yusoff, N. I. M., 2019. Engineering properties of crumb rubber modified dense-graded asphalt mixtures using dry process. In *IOP Conference Series: Earth and Environmental Science* (Vol. 220, No. 1, p. 012009). IOP Publishing , https://doi.org/10.1088/1755-1315/220/1/012009.

Hassan, N. A., Hainin, M. R., Yaacob, H., Ismail, C. R., and Yunus, N. Z. M., 2013. Evaluation on mix design and rutting resistance of dry mixed rubberised asphalt mixtures. *Jurnal Teknologi*, *65*(3), pp. 115-120, https://doi.org/10.11113/jt.v65.2156.

Hassana, N. A., Airey, G. D., Jaya, R. P., Mashros, N., and Aziz, M. M. A., 2014. A review of crumb rubber modification in dry mixed rubberised asphalt mixtures. *Jurnal Teknologi (Sci. Eng.)*, *4*, pp. 127-134, https://doi.org/10.11113/jt.v70.3501.

Huang, B., Mohammad, L. N., Graves, P. S., and Abadie, C., 2002. Louisiana experience with crumb rubber-modified hot-mix asphalt pavement. *Transportation Research Record*, 1789(1), pp. 1-13, https://doi.org/10.3141/1789-01.

Irfan, M., Ali, Y., Ahmed, S., and Hafeez, I., 2018. Performance evaluation of crumb rubber-modified asphalt mixtures based on laboratory and field investigations. *Arabian Journal for Science and Engineering*, 43, pp. 1795-1806, https://doi.org/10.1007/s13369-017-2729-2.

Issa, C. A., and Salem, G., 2013. Utilization of recycled crumb rubber as fine aggregates in concrete mix design. *Construction and Building Materials*, 42, pp. 48-52. https://doi.org/10.1016/j.conbuildmat.2012.12.054.

Issa, Y., 2016. Effect of adding waste tires rubber to asphalt mix. *International Journal of Scientific Research and Innovative Technology*, *3*(5), pp.61-68, https://doi.org/10.1007/s42947-023-00361-4.

Jamrah, A., Kutay, M. E., and Varma, S., 2015. Backcalculation of swollen crumb rubber modulus in asphalt rubber binder and its relation to performance. *Transportation Research Record*, 2505(1), pp. 99-107, https://doi.org/10.3141/2505-13.

Karakurt, C., 2015. Microstructure properties of waste tire rubber composites: an overview. *Journal of Material Cycles and Waste Management*, 17, pp. 422-433. https://doi.org/10.1007/s10163-014-0263-9.

Kocsis, J., Mészáros, L., and Bárány, T., 2013. Ground tyre rubber (GTR) in thermoplastics, thermosets, and rubbers. *Journal of Materials Science*, 48, pp.1-38.https://doi.org/10.1007/s10853-012-6564-2.

Khedaywi, T. S., Tamini, A. R., Al-Masaeid, H. R., and Khamaiseh, K., 1993. Laboratory investigation of properties of asphalt-rubber concrete mixtures. *Transportation Research Record*, (1417), http://worldcat.org/isbn/0309055652.

Lin, P., Huang, W., Tang, N., and Xiao, F., 2017. Performance characteristics of Terminal Blend rubberized asphalt with SBS and polyphosphoric acid. *Construction and Building Materials*, 141, pp. 171-182, https://doi.org/10.1016/j.conbuildmat.2017.02.138.

Liu, S., Zhou, S. B., Peng, A., Xuan, W., and Li, W., 2019. Analysis of the performance and mechanism of desulfurized rubber and low-density polyethylene compound-modified asphalt. *Journal of Applied Polymer Science*, 136(45), P. 48194, https://doi.org/10.1002/app.48194.

Mahrez, A., 2008. Properties and performance of stone mastic asphalt reinforced with glass fibre [Ph. D. thesis] Faculty of Engineering, University of Malaya, Kuala Lumpur, Malaysia.

Markl, E., and Lackner, M., 2020. Devulcanization technologies for recycling of tire-derived rubber: A review. *Materials*, 13(5), P. 1246, https://doi.org/10.3390/ma13051246.

Mashaan, N. S., 2012. The effect of crumb rubber modifier to the properties and rheological behaviour of asphalt binder. University of Malaya (Malaysia), https://doi.org/10.13140/RG.2.2.31131.13607.

Mashaan, N. S., Ali, A. H., Karim, M. R., and Abdelaziz, M., 2012. An overview of crumb rubber modified asphalt. *International Journal of Physical Sciences*, 7(2), pp. 166-170, https://doi.org/10.5897/IJPSX11.007.

Mashaan, N. S., Ali, A. H., Karim, M. R., and Abdelaziz, M., 2014. A review on using crumb rubber in reinforcement of asphalt pavement. *The Scientific World Journal*, 2014. https://doi.org/10.1155/2014/214612.

Mohammed, B. S., Hossain, K. M. A., Swee, J. T. E., Wong, G., and Abdullahi, M., 2012. Properties of crumb rubber hollow concrete block. *Journal of Cleaner Production*, 23(1), pp. 57-67. https://doi.org/10.1016/j.jclepro.2011.10.035.

Mohammed, F. A., Latief, R. H., and Albayati, A. H., 2024. Assessment of traditional asphalt mixture performance using natural asphalt from sulfur springs. *Journal of Engineering*, 30(01), pp. 54-73. https://doi.org/10.31026/j.eng.2024.01.04.

Mohammed, H. H., and Ali, A. S., 2023. Flexural behavior of reinforced rubberized reactive powder concrete beams under repeated loads. *Journal of Engineering*, 29(08), pp. 27-46. https://doi.org/10.31026/j.eng.2023.08.03.

Moreno, F., Rubio, M. C., and Martinez-Echevarria, M. J., 2012. The mechanical performance of dry-process crumb rubber modified hot bituminous mixes: The influence of digestion time and crumb rubber percentage. *Construction and Building Materials*, 26(1), pp. 466-474. http://dx.doi.org/10.1016/j.conbuildmat.2011.06.046.

Navarro, F. M., and Gámez, M. C. R., 2012. Influence of crumb rubber on the indirect tensile strength and stiffness modulus of hot bituminous mixes. *Journal of Materials in Civil Engineering*, 24(6), pp. 715-724. https://doi.org/10.1061/(ASCE)MT.1943-5533.

Nejad, F. M., Aghajani, P., Modarres, A., and Firoozifar, H., 2012. Investigating the properties of crumb rubber modified bitumen using classic and SHRP testing methods. *Construction and Building Materials*, 26(1), pp. 481-489. https://doi.org/10.1016/j.conbuildmat.2011.06.048.

Nikolaides, A., 2014. Highway engineering: Pavements, materials and control of quality. CRC Press.

Nunn, M., and Ferne, B. W., 2001. Design and assessment of long-life flexible pavements. *Transportation Research Circular*, *503*(12), pp. 32-49.

Oliver, J. W., 1981. Modification of paving asphalts by digestion with scrap rubber. *Transportation Research Record*, (821).

Padmarekha, A., and Krishnan, J. M., 2011. Experimental investigation on sol–gel transition of asphalt. *International Journal of Advances in Engineering Sciences and Applied Mathematics*, 3, pp. 131-139. https://doi.org/10.1007/s12572-011-0048-5.

Paje, S. E., Luong, J., Vázquez, V. F., Bueno, M., and Miro, R., 2013. Road pavement rehabilitation using a binder with a high content of crumb rubber: Influence on noise reduction. *Construction and Building Materials*, 47, pp. 789-798. http://dx.doi.org/10.1016/j.conbuildmat.2013.05.008.

Peralta, E. J. F., 2009. Study of the interaction between bitumen and rubber (Doctoral dissertation, Universidade do Minho (Portugal)).

Peralta, J., Silva, H. M., Machado, A. V., Pais, J., Pereira, P. A., and Sousa, J. B., 2010. Changes in rubber due to its interaction with bitumen when producing asphalt rubber. *Road Materials and Pavement Design*, 11(4), pp. 1009-1031. https://doi.org/10.1080/14680629.2010.9690317.

Pereira, P. A., Pais, J. C., Trichês, G., and Fontes, L. P. T. L., 2008. Laboratory optimization of continuous blend asphalt rubber. *Proceedings of 3rd European Pavement and Asset Management EPAM*, 3, pp. 1-12, https://doi.org/10.1680/jemmr.16.00037.

Presti, D. L., 2013. Recycled tyre rubber modified bitumens for road asphalt mixtures: A literature review. *Construction and Building Materials*, 49, pp. 863-881. https://doi.org/10.1016/j.conbuildmat.2013.09.007.

Salama, E. A., Amir, H., and Danil, N., 2020. Effect of Crumb Rubber Particles on the Properties of Asphalt. *Lecture Notes in Civil Engineering*, *59*. https://doi.org/10.1007/978-981-15-1193-6_5.

Sarsam, S. I., 2019. Moisture damage of warm mix asphalt concrete. *Journal of Engineering*, 25(6), pp. 101-116. https://doi.org/10.31026/j.eng.2019.06.08.

Sarsam, S. I., and Hasan, E. A., 2017. Evaluating water damage resistance of recycled asphalt concrete mixtures. *Journal of Engineering*, 23(1), pp. 156-168.

Šernas, O., Vaitkus, A., Kilaitė, D., and Škulteckė, J., 2023. The effect of the crumb rubber type and amount on dry process modified asphalt mixture and on low-temperature cracking and high-temperature rutting. *International Journal of Pavement Engineering*, 24(1), P. 2259574, https://doi.org/10.1080/10298436.2023.2259574.

Shen, J., Amirkhanian, S., Xiao, F., and Tang, B., 2009. Influence of surface area and size of crumb rubber on high temperature properties of crumb rubber modified binders. *Construction and Building Materials*, 23(1), pp. 304-310. https://doi.org/10.1016/j.conbuildmat.2007.12.005.

Shu, X., and Huang, B., 2014. Recycling of waste tire rubber in asphalt and portland cement concrete: An overview. *Construction and Building Materials*, 67, pp. 217-224. http://dx.doi.org/10.1016/j.conbuildmat.2013.11.027

Sienkiewicz, M., Borzędowska-Labuda, K., Wojtkiewicz, A., and Janik, H., 2017. Development of methods improving storage stability of bitumen modified with ground tire rubber: A review. *Fuel Processing Technology*, 159, pp. 272-279. http://dx.doi.org/10.1016/j.fuproc.2017.01.049.

Sienkiewicz, M., Kucinska-Lipka, J., Janik, H., and Balas, A., 2012. Progress in used tyres management in the European Union: A review. *Waste Management*, 32(10), pp. 1742-1751. http://dx.doi.org/10.1016/j.wasman.2012.05.010.

Singh, D., Mishra, V., Girimath, S. B., Das, A. K., and Rajan, B., 2019. Evaluation of rheological and moisture damage properties of crumb rubber–modified asphalt binder. *Advances in Civil Engineering Materials*, (1), pp. 477-496. https://doi.org/10.1520/ACEM20190045.

Tahami, S. A., Mirhosseini, A. F., Dessouky, S., Mork, H., and Kavussi, A., 2019. The use of high content of fine crumb rubber in asphalt mixes using dry process. *Construction and Building Materials,* 222, pp. 643-653. https://doi.org/10.1016/j.treng.2022.100145.

Tan, E. H., Zahran, E. M., and Tan, S. J., 2022. The optimal use of crumb rubber in hot-mix asphalt by dry process: a laboratory investigation using Marshall mix design. *Transportation Engineering*, *10*, P. 100145. https://doi.org/10.1016/j.treng.2022.100145.

Tefera, B. Y., Tadele, K., and Geremew, A.. 2018. Evaluation of the effect of rubber modified bitumen on asphalt performance. *American Journal of Civil Engineering*, *6*(3), 87-92. https://doi.org/10.11648/j.ajce.20180603.11.

Thodesen, C., Shatanawi, K., and Amirkhanian, S., 2009. Effect of crumb rubber characteristics on crumb rubber modified (CRM) binder viscosity. *Construction and Building Materials*, 23(1), pp. 295-303, https://doi.org/10.3390/su151813568.

Uriarte-Miranda, M. L., Caballero-Morales, S. O., Martinez-Flores, J. L., Cano-Olivos, P., and Akulova, A. A., 2018. Reverse logistic strategy for the management of tire waste in Mexico and Russia: Review and conceptual model. *Sustainability*, 10(10), P. 3398. https://doi.org/10.3390/su10103398.

Wang, H., Apostolidis, P., Zhu, J., Liu, X., Skarpas, A., and Erkens, S., 2021. The role of thermodynamics and kinetics in rubber–bitumen systems: a theoretical overview. *International Journal of Pavement Engineering*, 22(14), pp. 1785-1800. https://doi.org/10.1080/10298436.2020.1724289.

Wang, H., Dang, Z., Li, L., and You, Z., 2013. Analysis on fatigue crack growth laws for crumb rubber modified (CRM) asphalt mixture. *Construction and Building Materials*, *47*, pp. 1342-1349. http://dx.doi.org/10.1016/j.conbuildmat.2013.06.014.

Wang, H., Liu, X., Apostolidis, P., Erkens, S., and Scarpas, T., 2019. Numerical investigation of rubber swelling in bitumen. *Construction and Building Materials*, 214, pp. 506-515.

Wang, S., Cheng, D., and Xiao, F., 2017. Recent developments in the application of chemical approaches to rubberized asphalt. *Construction and Building Materials*, 131, pp. 101-113. http://dx.doi.org/10.1016/j.conbuildmat.2016.11.077.

Wang, T., Xiao, F., Zhu, X., Huang, B., Wang, J., and Amirkhanian, S., 2018. Energy consumption and environmental impact of rubberized asphalt pavement. *Journal of Cleaner Production*, 180, pp. 139-158. https://doi.org/10.1016/j.jclepro.2018.01.086.

Wang, W., Cheng, Y., Chen, H., Tan, G., Lv, Z., and Bai, Y., 2019. Study on the performances of waste crumb rubber modified asphalt mixture with eco-friendly diatomite and basalt fiber. *Sustainability*, 11(19), P. 5282, https://doi.org/10.3390/su11195282.

Wulandari, P. S., and Tjandra, D., 2017. Use of crumb rubber as an additive in asphalt concrete mixture. *Procedia Engineering*, *171*, 1384-1389. https://doi.org/10.1016/j.proeng.2017.01.451.

Xiang, Y., Xie, Y., Long, G., and Zeng, L., 2019. Ultraviolet irradiation of crumb rubber on mechanical performance and mechanism of rubberised asphalt. *Road Materials and Pavement Design*, 20(7), pp. 1624-1637. https://doi.org/10.1080/14680629.2018.1468801.

Zhang, D., Li, H., Tu, H., and Weng, Y., 2022. Investigation on the quasi-static mechanical properties and dynamic compressive behaviors of ultra-high performance concrete with crumbed rubber powders. *Materials and Structures*, 55(3), 104, https://doi.org/10.1617/s11527-022-01904-0.

Zheng, W., Wang, H., Chen, Y., Ji, J., You, Z., and Zhang, Y., 2021. A review on compatibility between crumb rubber and asphalt binder. *Construction and Building Materials*, 297, P. 123820. https://doi.org/10.1016/j.conbuildmat.2021.123820.

Zuo, P., Qu, S., and Shen, W., 2019. Asphaltenes: Separations, structural analysis and applications. *Journal of Energy Chemistry*, 34, pp. 186-207. https://doi.org/10.1016/j.jechem.2018.10.004.

ادخال فتات المطاط المعاد في الاسفلت – مراجعة شاملة

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الخلاصة

استخدام خلطات الاسفلت مع المواد المضافة اصبح مجال مهم لتحسين خواص الاسفلت. فتات المطاط المعاد تدويره او الاطارات المعادة هي احد هذه المواد التي اكتسبت اهتمام كبير حيث توفر خواص محسنة للخلطات الاسفلتية مع امتياز الكلفة القليلة والفعالية البيئية حيث انها تقلل من الاطارات التالفة التي ترمى كنفايات وتؤثر على البيئة. الدراسة تستكشف احدث المقالات في هذا المجال مع التركيز على مختلف الطرق المستخدمة لادخال فتات المطاط المعاد في ارضية المطاط. تم ملاحظة ان معظم المقالات ركزت على العملية الرطبة لادخال فتات المطاط المعاد في الاسفلت. هذه الطريقة معروفة بفعاليتها ولكنها تستهلك كمية قليلة من فتات المطاط المعاد عند مقارنتها بالعملية الجافة. العملية الجافة تتعامل مع فتات المطاط المعاد كمواد بديلة بدلاً عن اعتبارها مواد مضافة ولكن هذه الطريقة مستخدمة بصورة اقل من العملية الرطبة لتحسين خواص الاسفلت حيث ان لها تأثير قليل على رفع خواص الاسفلت. وهناك طريقة ثالثة وهي تجمع خواص الطريقتين المذكورة آنفاً.الحاجة لهذا البحث يتم تحفيزها عن طريق التحديات البيئة والاقتصادية المتصاعدة المرتبطة مع التخلص من نفايات الاطارات والتقادم المستمر للبنية التحتية للطرق. هذه الدراسة تشارك في تطوير حلول اقل كلفة, تقاوم الظروف ومستدامة لرصف الطرق عن طريق استكشاف فعالية وطرق ادخال فتات المطاط المعاد في الاسفلت.

الكلمات المفتاحية: فتات المطاط المعاد, الاستدامة, الطريقة الرطبة, الطريقة الجافة.