

# Utilization of Crumb Rubber as Additive in Asphalt Concrete for Sustainable Road Construction

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## Abstract

This study investigates the use of crumb rubber as an additive in modified asphalt concrete to enhance pavement performance and sustainability. Rutting, caused by repeated traffic loads and high temperatures, significantly impacts the lifespan and durability of asphalt pavements. The study examines the physical properties of crumb rubber-modified asphalt, with a focus on determining the optimal particle size and evaluating its performance under different loading and environmental conditions. Crumb rubber sizes of 2.36mm, 1.18mm, 0.425mm, and 0.075mm were incorporated into the asphalt mix, with each particle size mixed at a proportion of 8% by the weight of the total mixing for analysis. The results indicated that crumb rubber with a particle size of 0.075mm exhibited superior performance due to its larger surface area, which allowed better bonding with the bitumen binder. Performance tests, including Marshall Stability of 6176.07 kg, Marshall Flow of 4.15 mm, and stiffness of 2009.88 kg/mm, confirmed that 0.075mm was the optimal size, enhancing strength, flexibility, and durability while ensuring resistance to deformation and moisture damage. Although larger particle sizes of 2.36mm and 1.18mm provided better void filling with a void content of 15 percent, their overall performance was lower compared to 0.075mm, making it the most effective size for improved asphalt properties. These findings demonstrate the potential of crumb rubber as a sustainable additive in asphalt concrete, improving mechanical properties and contributing to the recycling of waste materials for road construction.

## 1. Introduction

Asphalt is usually used in road building because of its strength, affordability, and capacity to support high traffic volumes. However, conventional asphalt pavements are prone to various issues such as cracking, rutting, and potholes, which can significantly reduce their lifespan and increase maintenance costs [1]. As urbanization continues to rise, there is a pressing need for innovative materials that not only enhance the performance of asphalt but also contribute to environmental sustainability.

Rutting can form of permanent deformation in asphalt pavements, remains a significant challenge for road infrastructure worldwide [2]. It primarily results from the repeated application of traffic loads, particularly from heavy vehicles, combined with elevated pavement temperatures. As mentioned by Albayati [2], the severity of rutting is exacerbated by factors such as high axle loads and improper mix design. The increased frequency of traffic and extreme climatic conditions further contribute to the rapid deterioration of asphalt pavements, necessitating costly and frequent repairs [3].

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Additionally, asphalt tends to break down under heavy traffic and high temperatures, which can reduce its effectiveness, especially in regions with harsh climates. As mentioned by Liley [2] and Fontes [4], the rising demand for road infrastructure makes it clear that we need to find more sustainable and durable alternatives. Innovations like using recycled materials, crumb rubber, and eco-friendly binders show potential in improving the performance and reducing the environmental impact of asphalt [1][4].

Crumb rubber, derived from recycled tires, offers a promising alternative that addresses both performance and ecological concerns. Recent advancements in modified asphalt technologies have led to the development of high-performance mixtures that incorporate crumb rubber [5]. However, there is a lack of research in this area, particularly regarding the influence of crumb rubber particle size on the properties of asphalt concrete. In most cases, studies have concentrated on determining the optimal percentage of crumb rubber, while the impact of varying particle sizes has received far less attention. This gap in research limits the full potential of crumb rubber-modified asphalt, as particle size could significantly influence the mixture's performance, including its durability, resistance to cracking, and overall longevity. This study was carried out to focus on identifying the most suitable particle size of crumb rubber and ideal methods for the preparation of crumb rubber modified asphalt. Furthermore, the study will evaluate the performance characteristics of crumb rubber modified asphalt concrete under various loading and environmental conditions using several tests such as Marshall Stability and Flow, Penetration of Bitumen, Sieve Analysis and Bulk Specific Gravity. The tests conducted, such as Sieve Analysis, Penetration of Bitumen, Marshall Stability, and Bulk Specific Gravity, will establish a comprehensive understanding of how these modified mixtures perform compared to asphalt.

## 2. Methodology

### 2.1 Material

The aggregates are collected and purchased from Astana Hardware Trading Sdn Bhd at Bukit Gambir, Johor, where the coarse aggregates, specifically chipping 3/4" (20mm) stone, are obtained. Additionally, fine aggregates are collected from Makmal Teknologi Kejuruteraan Jalanraya, as shown at Fig 1 (a), to ensure their suitability for the asphalt concrete mix. Both types of aggregates are carefully selected to meet the required specifications for the study. Next, the type of bitumen with 60/70 grade was supplied by Makmal Teknologi Kejuruteraan Jalanraya. Furthermore, the crumb rubber used in the study was purchased at two different places to ensure that all the crumb rubber particles size are met the requirements of the study. A 10 kg quantity of crumb rubber with a particle size range of 1mm-3mm was purchased online from Impact Flex as shown in fig 1 (b). Additionally, fine-sized rubber powder was collected from Seng Huat Resources Sdn Bhd, located at Taman Industry Sri Sulong, Batu Pahat, Johor. Both types of crumb rubber were mixed and stored in a sealed container to prevent contamination.



**Fig. 1 :** (a) Aggregates are collected (b) Crumb Rubber with size of 1mm-3mm

### 2.2 Preparation

Sample preparation ensures accurate and reliable test results for asphalt concrete by adhering to ASTM standards. Materials such as aggregates, bitumen, and crumb rubber were measured and mixed precisely according to ASTM C136 for sieve analysis, ASTM D5 for bitumen penetration, ASTM D6926 for asphalt specimen preparation, ASTM D2726 for bulk specific gravity, and ASTM D1559 for Marshall Stability and Flow.

To analyze the crumb rubber particle size, the sample was oven-dried at 140°C for two hours to remove moisture. Sieves ranging from 3.35 mm to 0.075 mm were cleaned, dried, and stacked in descending order. A 1000

g crumb rubber sample was weighed and sieved for ten minutes using a mechanical shaker. The material retained on each sieve was weighed, and a gradation curve was plotted to determine particle size distribution.

For testing bitumen consistency, the bitumen was heated to 150°C for one hour, and 70 g of it was mixed with crumb rubber. The mixture was cooled for 24 hours and then placed in a water bath at 25°C for one hour. A 100 g needle was used to penetrate the bitumen for five seconds, and the penetration depth was measured and averaged to assess the bitumen’s consistency.

To determine the aggregate size distribution, sieves ranging from 20.0 mm to 5.0 mm were cleaned, stacked, and used for testing. A 5000 g aggregate sample was oven-dried at 150°C for three hours, weighed, and sieved for ten minutes using a mechanical shaker. The retained weights on each sieve were recorded, and a gradation curve was plotted.

Asphalt mixtures were prepared by heating aggregates to 150°C for three hours and bitumen for one hour. The heated materials, along with crumb rubber, were mixed at 140°C for four minutes to achieve a homogeneous blend. The mixture was then compacted in Marshall molds with 75 blows per side, forming cylindrical specimens of 101.6 mm in diameter and 63.5 mm in height. After compaction, the specimens were cooled for 24 hours to stabilize. Subsequent testing, including stability, flow, and void analysis, was performed as per ASTM D6927.

### 3. Result and Discussion

#### 3.1 Sieve Analysis of Crumb Rubber

The grain size distribution, as shown in Figure 4.1, reveals that the crumb rubber has a relatively uniform particle distribution, with a coefficient of uniformity (Cu) value of 6, which is above the typical threshold of 4. This indicates that the material is well-graded, meaning it contains a balanced mix of particle sizes. Such a well-graded material is desirable in asphalt applications, as it can contribute to better compaction and stability within the mixture. The coefficient of curvature (Cc) value of 0.91, which is close to 1, further suggests that the crumb rubber has a smooth gradation. This type of gradation is beneficial for achieving a more uniform distribution of particles, leading to better packing and improved asphalt density, which ultimately enhances the mechanical properties such as stiffness and resistance to deformation.

The specific grain diameters corresponding to the 10%, 30%, and 60% passing percentages (D10, D30, and D60) of 0.375 mm, 0.875 mm, and 2.250 mm, respectively, indicate that the crumb rubber exhibits a reasonable range of particle sizes. This allows for an effective interaction with the bitumen binder, which is crucial for improving the overall performance of the asphalt mixture. The uniform distribution and smooth gradation of the crumb rubber are key factors in enhancing the elasticity, resilience, and deformation resistance of the asphalt mix, making it suitable for durable and high-performing pavement applications.

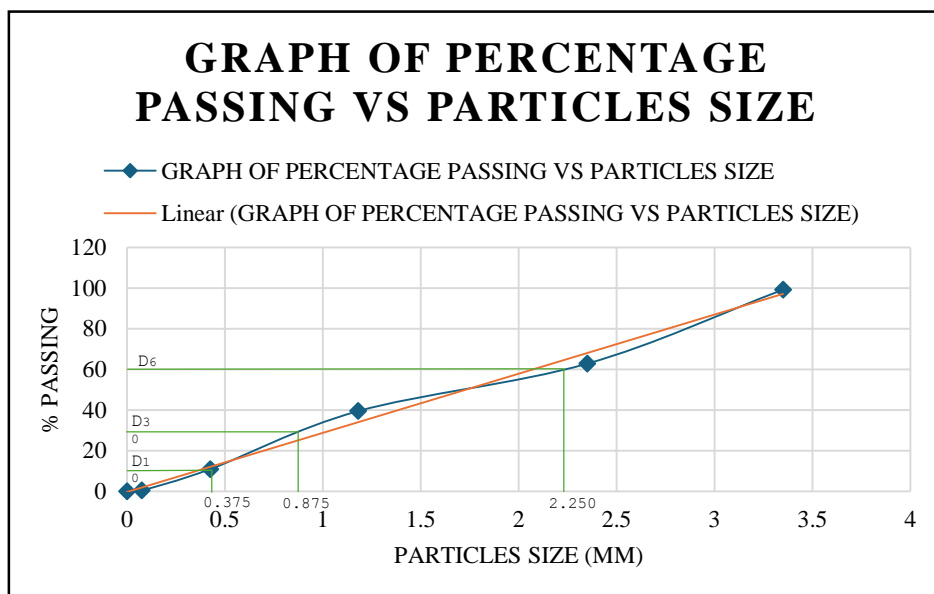


Fig. 2: Graph of Particle Size Distribution Curve of Crumb Rubber

#### 3.2 Sieve Analysis of Aggregates

The sieve analysis of the aggregates provides significant insight into their suitability for asphalt mixtures. The coefficient of uniformity (Cu) value of 1.73 suggests that the aggregate has a relatively uniform particle size distribution. In asphalt mix design, a higher Cu value, typically above 4, is preferred as it indicates a better balance of particle sizes that contribute to enhanced compaction and stability. A low Cu value, such as 1.73, implies that the material may lack the necessary variation in particle sizes, which could hinder its ability to effectively fill the voids within the asphalt mix. As a result, this could lead to reduced performance in terms of stability and durability of the final asphalt mixture.

Additionally, the coefficient of curvature (Cc) value of 0.81, which is outside the optimal range of 1.0 to 3.0, further confirms that the aggregate exhibits poor gradation. A Cc value outside this range typically indicates an uneven distribution of particle sizes, which can negatively affect the compaction process and result in a less stable mix. The grain diameters corresponding to the 10%, 30%, and 60% passing percentages (D10 = 5.50 mm, D30 = 6.50 mm, and D60 = 6.50 mm) support this finding, as the identical values for D30 and D60 suggest a lack of the necessary variety of particle sizes for optimal gradation.

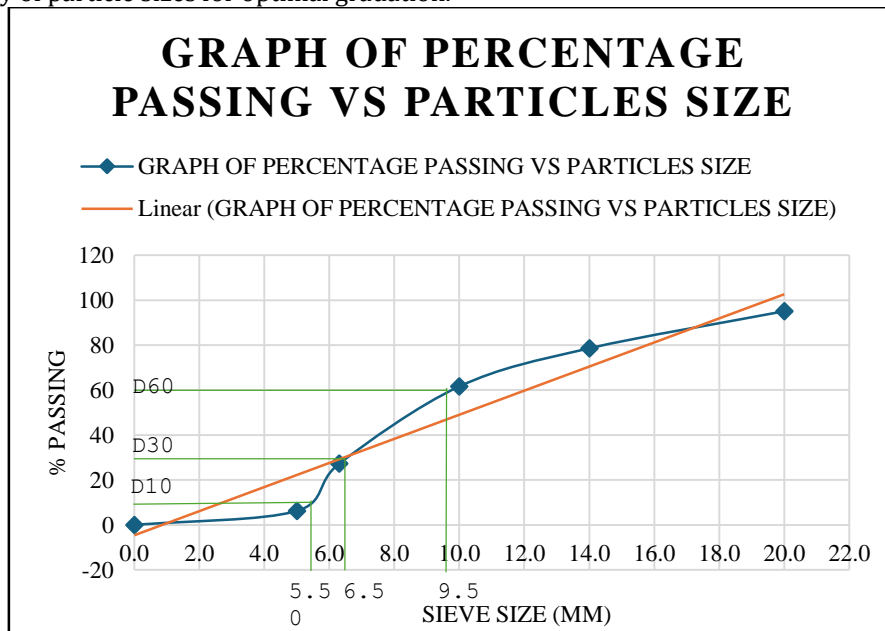


Fig. 3: Graph of Particle Size Distribution Curve of Aggregates

### 3.3 Penetration of Bitumen

The results presented demonstrate a clear relationship between crumb rubber content, particle size, and the penetration values of the modified bitumen. As the crumb rubber content increased and particle size decreased, the penetration values consistently decreased, indicating a rise in bitumen stiffness and resistance to deformation. For unmodified bitumen (0% crumb rubber), the penetration values were between 5.18 mm and 5.40 mm, reflecting its relatively soft consistency. However, with the addition of 8% crumb rubber, the penetration values decreased further, particularly with larger crumb rubber particles (2.36 mm), which ranged between 4.98 mm and 5.14 mm. Notably, as the particle size reduced to 0.075 mm, the penetration values dropped significantly, ranging from 3.77 mm to 3.92 mm. This decrease in penetration values suggests that finer crumb rubber particles contribute more effectively to increasing the hardness and consistency of the bitumen, enhancing its resistance to deformation and improving the overall durability and performance of the asphalt mixture.

### 3.4 Bulk Specific Gravity

The bulk specific gravity test, following ASTM D2726, revealed key insights into how crumb rubber particle size and content affect the density and void structure of asphalt mixtures. The bulk volume values, ranging from 492.8g to 643.6g, show that increasing crumb rubber content led to higher bulk volumes, indicating a denser mix. The percentage of volume voids in the mix aggregate (VMA) ranged from 15.20% to 27.1%, with larger crumb rubber particles (2.36mm and 1.18mm) yielding lower VMA values of 15.20% and 15.40%, demonstrating more effective void filling and a more compact mixture. The Voids in Filled Bitumen (VFB) ranged from 79.7% to 90.8%, indicating that higher binder content was needed as crumb rubber increased, enhancing resistance to deformation and improving durability. The air voids in the total mix (VTM) ranged from 2.7% to 4.4%, with the 2.36mm particle size having the lowest VTM value of 2.7%, further demonstrating a denser mix.

Bitumen Content + Crumb Rubber	IN AIR (g)	IN WATER (g)	BULK VOLUME (g)	VOIDS (%)	VFB (%)	VTM (%)
0%+7%	1158.0	665.1	492.8	21.4	79.7	4.4
(2.36mm) 8%+ 7%	1167.3	614.3	553.07	15.20	90.8	2.7
(1.18mm) 8%+ 7%	1157.3	602.7	554.6	15.4	90.7	2.8
(0.425mm) 8%+ 7%	1244.5	624.8	619.7	24.3	89.5	3.9
(0.075mm) 8%+ 7%	1296.4	652.7	643.6	27.1	89.4	4.2

Fig. 4: Bulk Specific Gravity Data

### 3.5 Marshall Stability and Flow

The Marshall Stability test results, which measure the maximum load before failure, showed values of 5114.21kg, 5944.70kg, 4293.55kg, 4923.43kg, and 6176.07kg for various crumb rubber particle sizes. The 0.075mm crumb rubber size demonstrated the highest Marshall Stability value at 6176.07kg, indicating the asphalt mix's superior ability to resist deformation under traffic loads. Higher stability values correlate with better resistance to rutting, suggesting that smaller particle sizes contribute to improved durability in asphalt mixtures. In addition, the Marshall Stiffness values, ranging from 1544.67kg/mm to 2009.88kg/mm, showed a similar trend. The 0.075mm crumb rubber size again recorded the highest stiffness value at 2009.88kg/mm, indicating enhanced resistance to deformation and improved structural integrity. These results highlight the benefits of finer crumb rubber particles in enhancing both stability and stiffness, contributing to more durable and resilient asphalt mixtures suitable for high-performance road construction.

Bitumen Content + Crumb Rubber Size	IN AIR (g)	IN WATER (g)	VOIDS (%)	VFB (%)	VTM (%)	STABILITY (kg)	FLOW (mm)	STIFFNESS (kg/mm)
0%+7%	1158.0	665.1	21.4	79.7	4.4	5114.21	3.04	1544.67
(2.36mm) 8%+ 7%	1167.3	614.3	15.20	90.8	2.7	5944.70	3.99	1672.47
(1.18mm) 8%+ 7%	1157.3	602.7	15.4	90.8	2.8	4293.55	4.00	1207.56
(0.425mm) 8%+ 7%	1244.5	624.8	24.3	89.5	3.9	4923.43	4.42	1465.66
(0.075mm) 8%+ 7%	1296.4	652.7	27.1	89.4	4.2	6176.07	4.15	2009.88

Fig. 5: Data of Marshall Stability and Flow

### Conclusion

Crumb rubber with a particle size of 0.075 mm demonstrated superior performance compared to larger particle sizes (2.36 mm, 1.18 mm, and 0.425 mm) when mixed with penetration grade bitumen. This finer particle size, due to its higher surface area, blended more effectively with the bitumen binder, resulting in enhanced elasticity, stiffness, and deformation resistance in the modified asphalt mix.

Laboratory tests, including Marshall Stability, Marshall Flow, and stiffness evaluations, confirmed the 0.075 mm crumb rubber as the most effective in improving the mechanical properties of the asphalt concrete. Its improved interaction with the bitumen binder yielded higher performance metrics, showcasing its suitability for creating durable and high-performing asphalt mixtures. Mohammed et al. [19] also noted that finer crumb rubber

particles improved the mechanical properties of asphalt, further supporting the idea that the 0.075 mm particle size yields superior results in terms of stiffness and resistance to deformation.

Performance evaluations under wet conditions revealed that crumb rubber sizes of 2.36 mm and 1.18 mm provided denser asphalt mixes with lower Voids in Mineral Aggregate (VMA), effectively filling voids. However, the 0.075 mm crumb rubber size offered the best overall results, combining elasticity, durability, and resilience under various loading and environmental conditions. Shyaamkrishnan et al. [20] also highlighted the stability of rubberized binders with smaller particle sizes, which improves the overall performance of the asphalt mix. This further underscores the potential of fine crumb rubber in creating durable and high-performing asphalt mixtures for sustainable road construction.

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