International Journal of Engineering and Science Applications

ISSN 2406-9833
Journal Homepage: http://pasca.unhas.ac.id/ijesca
Vol. 13, No. 1, May., 2026., pp 42 - 45

# Effect of Waste Tire Crumb Rubber on The Marshall Characteristics of Asphalt Concrete Wearing Course (AC-WC)

Donaltri Sampe Buntu[1], Irianto[1*], Didik S. Mabui[1]

[1] Civil Engineering Department, Faculty of Engineering, Yapis University, Jayapura, Indonesia

Corresponding Author Email: irian.anto@gmail.com

https://doi.org/10.18280/ijesca.123456

**Received: 18 February 2026**
**Accepted: 17 May 2026**

***Keywords:***
*Crumb rubber; AC-WC; Marshall stability; volumetric properties; sustainable pavement; waste tire*

**ABSTRACT**

Road infrastructure performance, particularly in Asphalt Concrete Wearing Course (AC-WC), often declines prematurely due to repeated traffic loading and environmental exposure. This study quantitatively evaluates the effect of waste tire crumb rubber as an aggregate additive on the Marshall characteristics and volumetric properties of AC-WC mixtures. Laboratory experiments were conducted using crumb rubber contents of 0%, 1%, 2%, and 3% by total aggregate weight with 60/70 penetration grade asphalt. The results indicate a non-linear relationship between crumb rubber content and mixture performance. Marshall stability increased from the control mixture (0%) to the optimum at 2%, exceeding the minimum specification requirement of 800 kg, before decreasing at 3% due to reduced particle interlocking. Flow values showed a consistent increase with crumb rubber addition, indicating enhanced flexibility, with values approaching the upper specification limits at higher contents. Consequently, the Marshall Quotient (MQ) exhibited a decreasing trend, reflecting a transition from stiff to more elastic behavior. Volumetric parameters, including VIM (within 3–5%), VMA (>15%), and VFB (>65%), satisfied specification limits at 0–2% crumb rubber but began to deviate at 3% content due to increased voids and reduced density. The optimum crumb rubber content was determined to be 2%, providing the best balance between stability, flexibility, and volumetric performance. These findings confirm that crumb rubber improves AC-WC performance while offering a sustainable solution for recycling waste tires in pavement engineering.

## 1. INTRODUCTION

Road infrastructure plays a vital role in supporting economic growth, regional connectivity, and mobility of people and goods. In developing regions, the quality and durability of road pavements are key indicators of infrastructure performance and service reliability. In Indonesia, flexible pavement systems are widely used, with Asphalt Concrete Wearing Course (AC-WC) serving as the top layer that directly resists traffic loads and environmental exposure. Due to its position, AC-WC must exhibit adequate stability, durability, flexibility, and resistance to deformation, fatigue cracking, and moisture damage. However, in practice, many pavements experience premature deterioration before reaching their design life. This condition is primarily caused by repeated heavy traffic loading, temperature variations, water infiltration, and suboptimal material performance. Conventional asphalt mixtures often exhibit limitations in balancing stiffness and flexibility, leading to issues such as rutting at high temperatures and cracking under repeated loading. Therefore, improving the mechanical performance and durability of AC-WC mixtures remains a critical challenge in pavement engineering.

In recent decades, the use of alternative and recycled materials in asphalt mixtures has gained increasing attention as part of sustainable infrastructure development. One promising material is crumb rubber derived from waste vehicle tires. Waste tires represent a significant environmental problem due to their non-biodegradable nature and increasing accumulation. The incorporation of crumb rubber into asphalt mixtures offers dual benefits: enhancing pavement performance and reducing environmental impact through material recycling. Crumb rubber is characterized by high elasticity, resilience, and resistance to deformation, making it suitable as an additive in asphalt mixtures. When incorporated into the aggregate matrix (dry process), crumb rubber can improve flexibility, increase resistance to fatigue cracking, enhance energy absorption, and reduce permanent deformation. Additionally, its rough surface texture may improve adhesion between aggregates and asphalt binder, contributing to better mixture stability. Nevertheless, excessive crumb rubber content may lead to reduced density and stability, indicating the need for determining an optimum dosage.

Previous studies have reported that crumb rubber modification can improve various performance aspects of asphalt mixtures; however, most research focuses on binder modification rather than its use as an aggregate additive. Limited studies have systematically evaluated the effect of crumb rubber content on Marshall characteristics and volumetric properties of AC-WC mixtures under standard specifications. Therefore, a comprehensive experimental investigation is required to quantify its influence and identify the optimum content. This study aims to evaluate the effect of waste tire crumb rubber as an additive to aggregates on the Marshall characteristics of AC-WC asphalt mixtures and to determine the optimum crumb rubber content that provides the best balance between stability, flexibility, and volumetric performance. The results of this study are expected to contribute to the development of sustainable pavement materials and provide practical insights for the application of crumb rubber in road construction.

## 2. RESEARCH METHODOLOGY

### 2.1 Research Approach

This study employed an experimental laboratory approach to evaluate the effect of waste tire crumb rubber as an additive to aggregates on the performance of Asphalt Concrete Wearing Course (AC-WC) mixtures. The evaluation focused on Marshall characteristics and volumetric properties to determine the optimum crumb rubber content.

### 2.2 Materials

The materials used in this study consisted of:

1. Asphalt Binder: Penetration grade 60/70 asphalt, commonly used in flexible pavement construction.
2. Aggregates: Coarse and fine aggregates meeting the requirements of the Bina Marga 2018 General Specifications (Revision 2).
3. Filler: Portland cement was used as mineral filler.
4. Crumb Rubber: Waste tire crumb rubber obtained from mechanically processed used vehicle tires, with particle sizes ranging from approximately 0.3–0.6 mm. The crumb rubber was used as an additive to the aggregate (dry process).

### 2.3 Mixtures Design

The asphalt mixture was designed as an AC-WC mixture based on the Bina Marga 2018 General Specifications (Revision 2). The optimum asphalt content (OAC) was determined prior to the addition of crumb rubber.
Crumb rubber was incorporated into the mixture with the following variations:

1. 0% (control mixture)
2. 1% of total aggregate weight
3. 2% of total aggregate weight
4. 3% of total aggregate weight

Each variation was prepared to evaluate the influence of crumb rubber content on mixture performance.

### 2.4 Specimens Preparation

The preparation of Marshall specimens followed standard procedures:

1. Aggregates and crumb rubber were dry-mixed to achieve uniform distribution.
2. Asphalt binder was heated to the mixing temperature and added to the mixture.
3. The mixture was thoroughly mixed until homogeneous.
4. Specimens were compacted using the Marshall compaction method with 75 blows per face.
5. The compacted specimens were allowed to cool at room temperature before testing.

### 2.5 Testing Methods

1. Marshall Test

Marshall testing was conducted to determine:

1. Stability (kg)
2. Flow (mm)
3. Marshall Quotient (MQ = Stability/Flow)

Testing procedures followed SNI 06-2489-1991 and were aligned with ASTM D1559/AASHTO T245 standards.

2. Volumetric Analysis

Volumetric properties of the asphalt mixtures were evaluated, including:

1. Void in Mix (VIM, %)
2. Void in Mineral Aggregate (VMA, %)
3. Void Filled with Bitumen (VFB, %)

These parameters were calculated based on bulk specific gravity and theoretical maximum density of the mixture.

### 2.6 Data Analysis

The experimental results were analyzed quantitatively to evaluate the relationship between crumb rubber content and mixture performance. The analysis included:

1. Comparison of Marshall stability, flow, and MQ values across all variations
2. Evaluation of volumetric properties against Bina Marga specification limits
3. Identification of performance trends (increase/decrease patterns)
4. Determination of the optimum crumb rubber content based on the balance between strength, flexibility, and volumetric criteria

The optimum content was selected as the mixture that satisfies all specification requirements while providing the best overall performance.

## 3. RESULTS AND DISCUSSION

### 3.1 Marshall Characteristics

The results of the Marshall test indicate that the addition of crumb rubber significantly affects the mechanical performance of AC-WC asphalt mixtures. Marshall stability showed an increasing trend with the addition of crumb rubber up to a certain level, followed by a decrease at higher content. The stability value increased from approximately 950 kg in the control mixture (0%) to about 1050 kg at 1% and reached a maximum of approximately 1100 kg at 2% crumb rubber content. However, at 3%, the stability decreased to around 980 kg. This behavior suggests that crumb rubber enhances aggregate interlocking and load resistance up to an optimum level, beyond which excessive rubber reduces mixture density and structural integrity.

Flow values exhibited a consistent increase from approximately 2.8 mm (0%) to 3.2 mm (1%), 3.6 mm (2%), and 4.2 mm (3%). This trend indicates improved flexibility due to the elastic nature of crumb rubber, which enhances the mixture's ability to accommodate deformation. However, excessive flow at higher rubber content may indicate reduced resistance to permanent deformation.

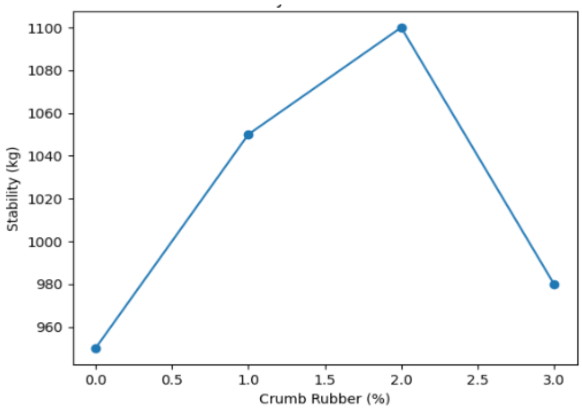


**Figure 1.** Variation of Marshall Stability with respect to crumb rubber content in AC-WC asphalt mixtures

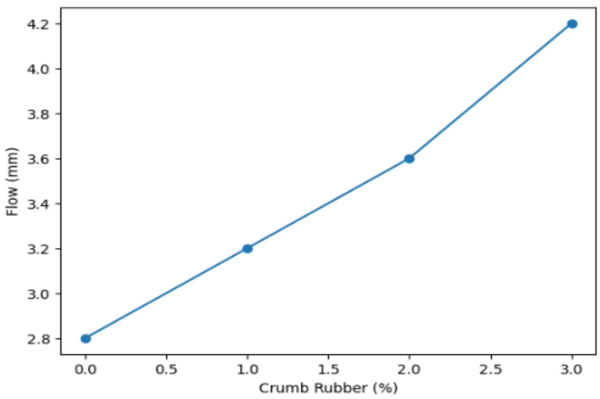


**Figure 2.** Variation of flow values with respect to crumb rubber content in AC-WC asphalt mixtures

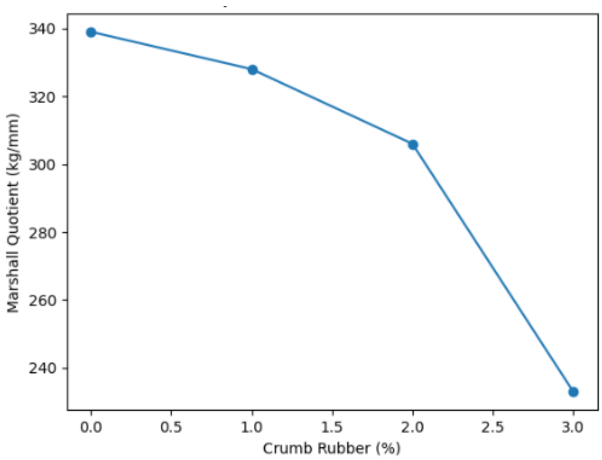


**Figure 3.** Variation of Marshall Quotient (MQ) with respect to crumb rubber content in AC-WC asphalt mixtures

The Marshall Quotient (MQ), representing the ratio of stability to flow, decreased from approximately 339 kg/mm (0%) to 328 kg/mm (1%), 306 kg/mm (2%), and 233 kg/mm (3%). This decline reflects a transition from a stiffer to a more flexible mixture. While moderate reduction in MQ is desirable for improved fatigue resistance, excessive reduction at 3% indicates loss of stiffness and load-bearing capacity.

### 3.2 Volumetric Properties

The volumetric analysis shows that crumb rubber content influences the internal structure of the asphalt mixture. The VIM values increased from approximately 3.5% (0%) to 3.8% (1%), 4.2% (2%), and 5.2% (3%). While values at 0–2% remained within the specification limits (3–5%), the value at 3% exceeded the allowable range, indicating excessive air voids and reduced compaction efficiency.

VMA values showed a slight increase from approximately 15.5% to 16.5%, indicating that the aggregate structure maintained sufficient void space to accommodate asphalt binder. All mixtures satisfied the minimum requirement (>15%), suggesting adequate aggregate skeleton stability. VFB values increased from approximately 68% (0%) to 70% (1%) and peaked at around 72% (2%), before decreasing to approximately 65% at 3%. The increase up to 2% indicates improved asphalt filling efficiency, while the decrease at 3% reflects reduced binder effectiveness due to increased voids.

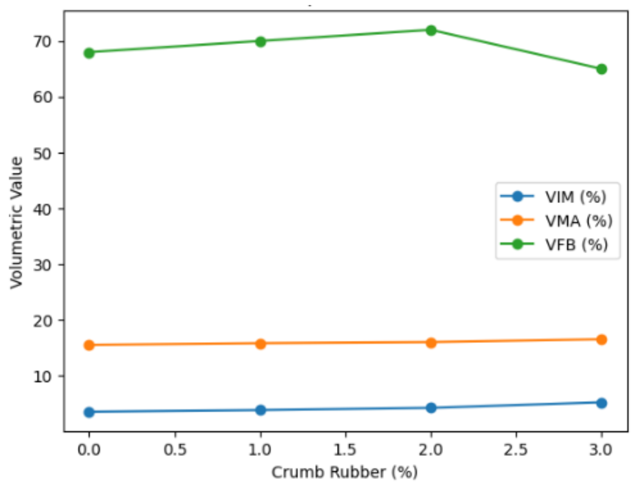


**Figure 4.** Variation of volumetric properties (VIM, VMA, and VFB) with respect to crumb rubber content in AC-WC asphalt mixtures

### 3.3 Integrated Performance Analysis

The combined evaluation of Marshall characteristics and volumetric properties reveals a clear relationship between crumb rubber content and mixture performance. At low to moderate contents (1–2%), crumb rubber improves both mechanical and volumetric performance by enhancing flexibility while maintaining sufficient stability and density.

However, at higher content (3%), the elastic nature of crumb rubber leads to increased air voids, reduced density, and decreased stability. This imbalance negatively affects the structural performance and durability of the mixture.

### 3.4 Optimum Crumb Rubber Content

Based on the overall analysis, the optimum crumb rubber content is determined to be 2% of the total aggregate weight. At this level, the mixture exhibits:

1. Maximum stability (~1100 kg)
2. Acceptable flow (~3.6 mm)
3. Balanced MQ (~306 kg/mm)
4. Volumetric parameters within specification limits (VIM, VMA, VFB)

This optimum condition represents the best balance between strength, flexibility, and durability.

### 3.5 Discussion

The findings confirm that crumb rubber acts as an elastomeric material that enhances the flexibility and energy absorption capacity of asphalt mixtures. This improvement is beneficial in reducing fatigue cracking and improving pavement resilience under repeated loading. However, excessive crumb rubber content reduces compaction efficiency and disrupts the internal structure of the mixture, leading to performance degradation. These results highlight the importance of optimizing crumb rubber dosage to achieve a balance between stiffness and flexibility. The use of crumb rubber at an optimum level not only improves pavement performance but also contributes to sustainable construction practices by recycling waste tire

## 4. CONCLUSIONS

This study investigated the effect of waste tire crumb rubber as an additive to aggregates on the Marshall characteristics and volumetric properties of AC-WC asphalt mixtures. Based on the experimental results and analysis, the following conclusions can be drawn:

1. The addition of crumb rubber significantly influences the mechanical performance of AC-WC mixtures. Marshall stability increased with crumb rubber content up to 2%, reaching the maximum value, and then decreased at 3% due to reduced mixture density and weakened aggregate interlocking.
2. Flow values increased consistently with increasing crumb rubber content, indicating enhanced flexibility and deformation capacity of the mixture. However, excessive flow at higher content (3%) suggests a reduction in resistance to permanent deformation.
3. The Marshall Quotient (MQ) decreased with increasing crumb rubber content, reflecting a transition from a stiffer to a more flexible mixture. While moderate reduction improves fatigue resistance, excessive reduction leads to a loss of structural stiffness.
4. Volumetric properties were significantly affected by crumb rubber addition. VIM increased with higher rubber content, exceeding specification limits at 3%, while VMA remained within acceptable limits. VFB reached its optimum value at 2% but decreased at higher content, indicating reduced asphalt filling efficiency.
5. The optimum crumb rubber content was determined to be 2% of the total aggregate weight, providing the best balance between stability, flexibility, and volumetric properties while satisfying all specification requirements.
6. The use of waste tire crumb rubber demonstrates strong potential as a sustainable material in asphalt pavement, contributing to improved performance and environmental benefits through the recycling of non-biodegradable waste.

ACKNOWLEDGMENT

The authors would like to express their sincere appreciation to the Civil Engineering Laboratory of Universitas Yapis Papua for providing the experimental facilities and technical support essential to this research. Special thanks are extended to the Graduate School of Universitas Hasanuddin, Makassar, for academic guidance and collaboration throughout the study.

## REFERENCES

[1] American Association of State Highway and Transportation Officials (AASHTO). *T 245: Resistance to Plastic Flow of Asphalt Mixtures Using Marshall Apparatus*. Washington, DC: AASHTO.

[2] ASTM International. *ASTM D6927: Standard Test Method for Marshall Stability and Flow of Asphalt Mixtures*. West Conshohocken, PA: ASTM International.

[3] Direktorat Jenderal Bina Marga. *Spesifikasi Umum 2018 untuk Pekerjaan Konstruksi Jalan dan Jembatan (Revisi 2)*. Jakarta: Kementerian Pekerjaan Umum dan Perumahan Rakyat, 2020.

[4] Hidayat, K., et al. "A Change in the Index of Retained Strength in the AC-WC Asphalt Mixture with Addition of Used Tire Rubber Waste (Crumb Rubber)." *Jurnal Manajemen dan Praktik Teknik Sipil*, 2023.

[5] Irfan, M. I., et al. "Effect of Crumb Rubber from Waste Tires on Asphalt Mixture Characteristics." *Fondasi: Jurnal Teknik Sipil*, 2025.

[6] Putra, B. H. R., et al. "Durability of Asphalt Concrete Mixture (AC-WC) Using Crumb Rubber from Waste Tires." *Jurnal Teknik Sipil*, 2024.

[7] Sukirman, S. *Beton Aspal Campuran Panas*. Bandung: Granit, 2003.

[8] The Asphalt Institute. *MS-2 Asphalt Mix Design Methods*. Lexington, KY: Asphalt Institute.

[9] Wearing Course (AC-WC) with Crumb Rubber Mixture. *Jurnal Transportasi Sistem*, Institut Teknologi Bandung, 2019.

[10] Studi Perbandingan Karakteristik Marshall pada Campuran Aspal dengan Crumb Rubber Metode Dry Mix dan Wet Mix. *Jurnal Transportasi*, 2025.

[11] Lapian, F. E. P., & Tumpu, M. (2025). Optimizing Asphalt Mixture Performance with Modified Buton Asphalt and Recycled PET using the Response Surface Methodology. *Engineering, Technology & Applied Science Research*, *15*(2), 21440-21449.