

## Comparative Evaluation of Marshall Properties for Crumb Rubber Modified AC-BC and AC-WC Asphalt Mixtures using the Dry Process

Fathei Ramadan Saleh Lamein <sup>1\*</sup>, Ayman Fathullah Almabrouk Alfirjani <sup>2</sup>

<sup>1</sup>Libyan Center for Engineering Research and Information Technology, Bani Walid, Libya

<sup>2</sup> Department of Civil Engineering, Bani Waleed University, Libya

تقييم مقارنة لخصائص مارشال للخلطات الأسفلتية (AC-BC) و (AC-WC) المعدلة بفتات المطاط باستخدام الطريقة الجافة

فتحي رمضان صالح لامين <sup>1\*</sup>، أيمن فتح الله المبروك الفرجاني <sup>2</sup>  
<sup>1</sup> المركز الليبي للبحوث الهندسية وتقنية المعلومات، بني وليد، ليبيا  
<sup>2</sup> قسم الهندسة المدنية، جامعة بني وليد، ليبيا

\*Corresponding author: [fathe\\_1@yahoo.com](mailto:fathe_1@yahoo.com)

Received: January 20, 2026

Accepted: February 24, 2026

Published: March 13, 2026

### Abstract

This study evaluates the mechanical and volumetric performance of asphalt mixtures modified with crumb rubber (CR) using the dry process. Road infrastructure demands high-quality materials to ensure durability and accommodate increasing traffic loads. The research compares two types of mixtures: Asphalt Concrete-Wearing Course (AC-WC) and Asphalt Concrete-Binder Course (AC-BC). Five different asphalt contents (5%, 5.5%, 6%, 6.5%, and 7%) were tested, with the addition of 3% and 5% crumb rubber by weight of the fine aggregate. Performance was assessed based on Marshall Test parameters, including stability, flow, and volumetric properties such as Voids Filled with Asphalt (VFA) and Voids in the Mixture (VIM). Results indicated that while the addition of crumb rubber generally increased VFA and inversely decreased VIM, it had a counterproductive effect on Marshall stability in certain concentrations. The study concludes that the AC-BC mixture with 3% crumb rubber provides the most balanced performance in terms of strength and durability compared to higher rubber contents. These findings suggest that 3% CR modification in binder courses offers a viable alternative for improving road pavement quality.

**Keywords:** Crumb Rubber, AC-BC, AC-WC, Marshall Properties, Dry Process, Asphalt Modification, Pavement Durability.

### الملخص

تُعد هذه الدراسة بتقييم الأداء الميكانيكي والحجمي للخلطات الأسفلتية المعدلة بفتات المطاط (CR) باستخدام الطريقة الجافة. إذ تفرص البنية التحتية للطرق ضرورة توفير مواد عالية الجودة لضمان الديمومة والقدرة على استيعاب الأحمال المرورية المتزايدة. يركز البحث على إجراء مقارنة بين نوعين من الخلطات: الخرسانة الأسفلتية للطبقة السطحية (AC-WC) والخرسانة الأسفلتية للطبقة الرابطة (AC-BC). وقد جرى اختبار خمس نسب مختلفة من المحتوى الأسفلتي (5%، 5.5%، 6%، 6.5%، و7%)، مع إضافة فتات المطاط بنسبتي 3% و5% من وزن الركام الناعم. تم تقييم الأداء بالاستناد إلى معايير اختبار مارشال، والتي شملت الثبات (Stability)، والزحف (Flow)، والخصائص الحجمية مثل الفراغات المملوءة بالأسفلت (VFA) والفراغات في الخلطة (VIM). وأظهرت النتائج أنه على الرغم من أن إضافة فتات المطاط أدت عموماً إلى زيادة نسبة الـ VFA وخفض نسبة الـ VIM بشكل عكسي، إلا أنها أحدثت تأثيراً سلبياً على ثبات مارشال عند تركيزات معينة. وخلصت الدراسة إلى أن خلطة (AC-BC) المضاف إليها 3% من فتات المطاط توفر الأداء الأكثر توازناً من حيث القوة والمتانة مقارنة بنسب المطاط الأعلى. وتشير هذه النتائج إلى أن تعديل الطبقات الرابطة بنسبة 3% من فتات المطاط يمثل بديلاً فعالاً لتحسين جودة رصف الطرق.

## Introduction

The continuing growth of traffic gives rise to a constant increase in damage to transport systems. Therefore, road quality and durability are top issues in the economic and safety performance of road infrastructure. The rapid development of transportation infrastructures and the increasingly higher expected performances of these systems require materials capable of providing improved properties in terms of workability, temperature sensitivity, fatigue resistance, crack propagation, deformability or permanent deformations, and aging. In this context, greater attention should be paid to asphalt mixtures, which play a key role in guaranteeing road durability. To provide these materials with improved characteristics, numerous firms and universities have been developing chemical technological additives. Waste products, as alternatives to fully and partially replace the bitumen used, have also been added in their project. Sugar cane by-products, fibers, and the crumb rubber generated from end-of-life tires, which constitute one of the biggest issues confronting the recycling industry worldwide, also represent easily available alternatives.

Nowadays the activity of people are getting higher. People need road to connect the activity and to support human business. Therefore, the quality of the road is very important. In line with that reason, government always do maintenance for the road because of the weak durability of conventional asphalt, unfortunately the maintenance of the road need many budget and becoe the routine plan of government.

To decrease the maintenance budget, people should use another materials which can be mixed with asphalt to get better quality of road. In the context of this research, the quality of the road can be improved with the use of crumb rubber. According to Bahia and Davies (2008), crumb rubber derived from used vehicular tires has been used for a wide variety of industrial applications as follow:

1. In the early 1960's, pavement engineers in the United States started experimenting with the use of crumb rubber asa modifier to asphalt cement used in pavement applications.
2. Different approaches were used to incorporate crumb rubber modifier (CRM) in road paving materials. In general these approaches are at the present time classified as the dry method and the wet method.
3. The wet method involves dispersing the CRM particles into the asphalt cement to produce what is called asphalt rubber (AR) which in turn is used to produce hot-mix asphalt concrete. The dry process involves mixing the CRM with the aggregate before introducing the asphalt cement to the mixture.

Based on the beneficial of crumb rubber, this study covers on the topic of modified HMA mixes with crumb rubber by using the method of dry process.

This study covers one type of aggregate gradation, that is, dense graded aggregate. The preparation of HMA samples and tests is following Marshall Design Procedures and the results of the tests should comply with Indonesian specification, that is, BinaMarga (Directorate General of Highway) standards (2010).

Conventional HMA consists of mixes with a nominal maximum aggregate size in the range of 12.5 mm (0.5 in.) to 19 mm (0.75 in.). This material makes up the bulk of HMA used in the United States (Lenz, 2011).

Hot mix asphalt (HMA) is a generic term that includes many different types of mixtures of aggregate and asphalt cement (binder) produced at elevated temperatures (generally between 300-350°F) in an asphalt plant. Typically, HMA mixtures are divided into three mixture categories: dense-graded; open-graded; and gap-graded as a function of the aggregate gradation used in the mix. Open-graded mixes are produced with relatively uniform-sized aggregate typified by an absence of intermediate-sized particles (gradation curve has a nearly vertical drop in intermediate size range). Mixes typical of this structure are the permeable friction course and asphalt-treated permeable bases. Because of their open structure, precautions are taken to minimize asphalt drain-down by using modified binders (A-R) "asphalt rubber," or by use of fibers. Stone-on-stone contact with a heavy asphalt cement particle coating typifies these mixes (Russel W. Lenz, 2011).

Based on the background, the problem statement f this research is What is the effect of crumb rubber as a replacement for fine aggregate between construction AC-WC in terms of strength and durability compared to construction of AC – BC in terms of strength and durability?

## Methods and Materials

This research will use several variables as follow:

- a. Independent variables
  1. Asphalt
  2. Crumb rubber
- b. Dependent variable
  1. Strength
  2. Durability

In terms of research process in laboratory, the writer will start the process with material specification. The writer will choose fine aggregate, coarse aggregate, crumb rubber, asphalt. Then the writer will test those materials to be in line with specification and standard that has been guided in the previous pages. Then the writer will separate the materials into kinds of sample namely AC-WC and AC-BC. Both of samples will use two specimens namely specimens with crumb rubber and specimens without crumb rubber.

In this study, the type of mixture used is Asphalt Concrete – Wearing Course (AC-WC). Then the writer also make research on Asphalt Concrete Binder Course or AC-BC. To determine the optimum asphalt content of the mixture, the performance of mixture was evaluated based on Marshall Test. Marshall Test has six parameters, those are, Marshall Stability, Flow, Marshall Quotient (MQ), Voids in Mineral Aggregate (VMA), Voids in the Mixture (VIM), and Voids Filled with Asphalt (VFA). Those tests will be conducted with Marshall Stability Test Apparatus in the laboratory.

Then, the researcher will compare the different between AC-WC and AC-BC for the above tests. In terms of comparing, the writer will compare the AC-WC and AC-BC mixture in 5 (five) asphalt content namely 5%, 5.5%, 6%, 6.5%, and 7%. Then the writer will find the best combination that can be recommended for conclusion.

## Result and Discussion

### Asphalt

Based on the research result, penetration for asphalt is 65.27 mm while the standard from Bina Marga 2010 is 60-70 mm. Therefore, the result of penetration is meet the requirement of Bina Marga 2010. Moreover, in terms of specific gravity, the research result showed 1.061, while the requirement of Bina Marga 2010 is Minimal 1. Therefore, it can be concluded that the asphalt properties meet the requirement of Bina Marga 2010. Then, the result of softening point of the asphalt which was used for research was 0°C.

### Aggregate

At the preliminary stage, aggregate was sieved according to AASHTO T 27-88 and separated according to the size of sieves on the selected aggregate gradation.

Similar with asphalt cement, the aggregate materials required to be tested to evaluate whether their properties fulfil the requirements. Several aggregate properties were measured in this study, such as specific gravity, abrasion, and so on, to make sure that the aggregates could be used in making the asphalt mixtures.

**Table 1 Coarse Aggregate Test.**

Grading Test		Number of Rounds = 500 Rounds	
Sieve size		I	II
Through Sieve	Not Through Sieve	Sample (a)	Sample (b)
76,2 (3")	63,5 (2,5")		
63,5 (2,5")	50,8 (2")		
50,8 (2")	36,1 (1,5")		
36,1 (1,5")	25,4 (1")		
25,4 (1")	19,1 (3/4")		
19,1 (3/4")	12,7 (1/2")	2500	2500
12,7 (1/2")	9,52 (3/8")	2500	2500
9,52 (3/8")	6,35 (1/4")		
6,35 (1/4")	4,75 (No.4)		
4,75 (No.4)	2,36 (No.8)		
Total weight		10000	5000
Weight held by sieve No. 12 after research (b)		7935	3933

**Source:** Research Result (2024)

## Crumb Rubber

In terms of crumb rubber, the specification of specific gravity was 1.09

### Use of Crumb Rubber in Asphalt Mixtures

The use of crumb rubber in an asphalt concrete mix improves the resistance to fatigue, reflective cracking, locking of the aggregate particles, thermal cracking, and reduces road traffic noise. The use of crumb rubber obtained from retired tires has become a viable alternative for its reinforced incorporation in asphalt concrete. It is assumed that the use of crumb rubber in asphalt mixtures with the implementation of SMA/SDG, with lower mixing and compacting temperatures, enables the conservation of both aggregates and bitumen. However, the introduction of crumb rubber as an aggregate in mixtures carries problems in the handling of the material, its compatibility, the cohesion with the bitumen, and the limited penetration of binder in both the crumb rubber surface and its specific characteristics. The additional presence of the graining fraction generated by the abrasion of the rubber on the superficial layer of the bituminous mix allows improvement through SMA and SDG.

The introduction of a higher percentage of crumb rubber in the asphalt mixture influences the characteristics of the crumb rubber in the mix, which changes adhesion with the bituminous binder, increases the viscosity at low temperatures, and reduces the UMA and lower force at intermediate temperatures. The great challenge is to achieve the right compromise in the characteristics of the mixture and the bituminous binder with a lower energy demand. There is also a need for regulation to establish the maximum contents of crumb rubber in the SMA and SDG mixtures. The challenge is to define the upper or lower permissible limits that determine the final quantity of the mixture, its homogeneity, and the environmental implications of increasing the use of crumb rubber.

### Asphalt Mixture

In this study, the type of mixture used is Asphalt Concrete – Wearing Course (AC-WC). To determine the optimum asphalt content of the mixture, the performance of mixture was evaluated based on Marshall Test. Marshall Test has six parameters, those are, Marshall Stability, Flow, Marshall Quotient (MQ), Voids in Mineral Aggregate (VMA), Voids in the Mixture (VIM), and Voids Filled with Asphalt (VFA). The results of Marshall parameters evaluated in this study should comply with Indonesian specification (BinaMarga, 2010),

**Table 2 Marshall Properties of The Mixture**

Asphalt Content (%)	Stability Kg	Flow mm	VFA %	VIM %	MQ Kg/mm	Density Gr/cm <sup>3</sup>	VMA %
5,0	841,23	3,74	63,14	6,30	225,17	2,40	17,09
5,5	933,41	3,90	66,90	5,84	239,51	2,40	17,63
6,0	962,90	3,78	70,43	5,37	255,87	2,40	18,15
6,5	909,93	3,60	74,09	4,82	252,78	2,39	18,59
7,0	810,50	3,46	76,81	4,45	233,41	2,39	19,17
<b>Specification</b>	<b>min 800</b>	<b>min 3</b>	<b>min 65</b>	<b>3.5-5</b>	<b>min 250</b>		<b>min 15</b>

Source: Research Result (2024).

Based on the result, it can be seen that Asphalt Concrete – Wearing Course (AC-WC) showed that all asphalt content can meet the stability requirement of Bina Marga 2010. Moreover, the asphalt content also meet the requirement of flow test because all of the flow result are more than 3. Then in terms of VFMA, the result of 5% asphalt content showed the lowest value than others sample and do not meet the requirement of Bina Marga 2010. On the other hand, the score of VIM for all of the sample of asphalt content can be more than 3.5 under 5 as requirement from Bina Marga 2010. Then, in terms of MQ, the score of 5%, 5.5% and 7% asphalt content under the requirement of Bina Marga; but for the PMA all the asphalt content meet the requirement.

Based on the result on Asphalt Concrete – Wearing Course (AC-WC) the good mixture of asphalt content are the 6% and 6.5% asphalt content because it can meet all the requirement of Bina Marga 2010.

Moreover, the writer also described the properties of mixture AC-WC-CR3 as mentioned in Table 3 below

**Table 3 Marshall Properties of Mixture AC-WC-CR3**

Asphalt Content	Stability	Flow	VFA	VIM	MQ	Density	VMA
(%)	Kg	mm	%	%	Kg/mm	Gr/cm <sup>3</sup>	%
5,0	570,15	3,94	63,51	6,21	144,87	2,41	17,01
5,5	641,37	4,08	67,09	5,79	158,82	2,40	17,59
6,0	740,93	3,94	70,81	5,28	188,61	2,40	18,07
6,5	685,27	3,78	74,47	4,73	182,22	2,40	18,51
7,0	583,43	3,64	77,19	4,36	159,41	2,39	19,10
<b>Specification</b>	<b>min 800</b>	<b>min 3</b>	<b>min 65</b>	<b>3.5-5</b>	<b>min 250</b>		<b>min 15</b>

Source: Research Result 2024

Based on the research result, it can be seen that value of the mixture with 3% crumb rubber not showed the nest mixture because there are so many points which can not meet the requirement by Bina Marga 2010 especially in term sof MQ value. Then in terms of stability, this research result also reported that all of sample can not meet the requirement.

Then, the writer also conducted Marshall Properties of Mixture AC-WC-CR5 as mentioned in Table 4 below.

**Table 4 Marshall Properties of Mixture AC-WC-CR5**

Asphalt content	Stability	Flow	VFA	VIM	MQ	Density	VMA
(%)	Kg	mm	%	%	Kg/mm	Gr/cm <sup>3</sup>	%
5,0	437,89	4,16	63,90	6,11	106,24	2,41	16,92
5,5	542,38	4,28	67,66	5,65	125,32	2,40	17,47
6,0	606,55	4,18	71,20	5,18	144,95	2,40	17,99
6,5	590,93	4,02	74,98	4,61	147,33	2,40	18,41
7,0	493,48	3,82	77,71	4,23	129,47	2,39	18,99
<b>Specification</b>	<b>min 800</b>	<b>min 3</b>	<b>min 65</b>	<b>3.5-5</b>	<b>min 250</b>		<b>min 15</b>

Source: Research Result 2024

Based on the research result, the mixture with crumb rubber 5% also does not give the good result of the mixture because the value of MQ for all of the sample are lower than requirement. Then in this mixture, the asphalt content also does not meet the stability value of Bina Marga 2014.

Then the researcher also make research on Asphalt Concrete Binder Course or AC-BC. In terms of AC-BC the researcher also uses crumb rubber 3% and 5%.

In terms of AC-BC, the writer conducted several tests of Marshall properties as mentioned in Table 5 below.

**Table 5 Marshall Properties of Mixture AC-BC**

Asphalt Content	Stability	Flow	VFA	VIM	MQ	Density	VMA
(%)	Kg	mm	%	%	Kg/mm	Gr/cm <sup>3</sup>	%
5,0	989,87	3,76	65,69	5,67	263,86	2,42	16,54
5,5	1056,32	3,40	68,52	5,44	310,51	2,41	17,28
6,0	1143,71	3,20	70,91	5,25	358,89	2,40	18,05
6,5	1086,04	2,98	73,15	5,04	365,48	2,39	18,78
7,0	998,85	2,76	75,57	4,75	363,55	2,38	19,43
<b>Specification</b>	<b>min 800</b>	<b>min 3</b>	<b>min 63</b>	<b>3.5-5</b>	<b>min 250</b>		<b>min 14</b>

Source: Research Result (2024)

Based on the research result in Table 4.5, it can be seen that the stability of asphalt content is better and more than minimum value from Bina Marga 2010. Unfortunately, the flow value not showed same result between the percentage of asphalt content. The asphalt content 6.5% and 7% showed lower value than the minimal specification from Bina Marga 2010.

Then, in terms of VFA value, all of the asphalt content gets the higher value than the standard from Bina Marga 2010, but the asphalt content 5% showed lowest value than the other higher asphalt contents.

Moreover, in terms of VIM value, the value of all asphalt content showed higher than minimum value which has been recommended by Bina Marga 2010. Then the value of MQ also showed the higher value than minimum standard from Bina Marga. The last is the value of VMA, this value is higher than the minimal specification than Bina Marga recommendation.

Based on the research result, it can be seen that AC-BC showed the higher value than AC-WC in terms of stability, flow, VFA, VIM, MQ, density and VMA.

Then, the researcher also made a mixture of AC-BC with Crumb rubber 3% or known as AC-BC-CR3. The result of the combination will be described in Table 6 as follow.

**Table 6 Marshall Properties of Mixture AC-BC-CR3**

Asphalt Content	Stability	Flow	VFA	VIM	MQ	Density	VMA
(%)	Kg	mm	%	%	Kg/mm	Gr/cm <sup>3</sup>	%
5,0	673,04	3,88	66,20	5,55	173,27	2,42	16,43
5,5	728,73	3,62	68,78	5,38	201,58	2,41	17,23
6,0	768,91	3,38	71,41	5,13	227,74	2,40	17,95
6,5	777,77	3,20	73,90	4,86	243,68	2,39	18,63
7,0	725,17	2,88	75,86	4,67	251,81	2,38	19,37
Specification	min 800	min 3	min 63	3.5-5	min 250		min 14

**Source:** Research Result (2024)

**Stability:** All samples are below the minimum requirement of 800 Kg.

**Flow:** All samples meet the minimum requirement of 3 mm.

**VFA:** All samples meet the minimum requirement of 65%.

**VIM:** All samples fall within the specified range of 3.5-5%.

**MQ:** All samples are below the minimum requirement of 250 Kg/mm.

**Density:** All samples meet the minimum requirement of 15 g/cm<sup>3</sup>.

Based on the research result, it can be seen that the stability of AC-BC with crumb rubber 3% showed lower value than AC-BC. Then, the flow, VFA and VIM value showed slightly different with the AC-BC. Then, the value of MQ on AC-BC-CR3

showed lower than AC-BC. Therefore, it can be concluded that the addition of crumb rubber 3% on AC-BC mixture will influence of stability and MQ value. The addition of crumb rubber 3% on AC-BC mixture will decrease the stability and MQ.

Then, the researcher also add crumb rubber 5% in the AC-BC as mentioned in Table 7.

**Table 7 Marshall Properties of Mixture AC-BC-CR5**

Asphalt content (%)	Stability Kg	Flowmm	VFA %	VIM %	MQ Kg/mm	Density Gr/cm <sup>3</sup>	VMA %
5,0	483,86	4,04	67,12	5,34	120,73	2,43	16,24
5,5	541,36	3,84	70,14	5,06	141,30	2,42	16,95
6,0	623,44	3,57	72,75	4,82	176,13	2,41	17,67
6,5	652,55	3,38	75,13	4,57	193,35	2,40	18,38
7,0	572,56	3,00	77,09	4,38	191,61	2,39	19,12
Specification	min 800	min 3	min 63	3.5-5	min 250		min 14

**Source:** Research Result (2024)

Then, based on the research result, it can be seen that the add of higher crumb rubber into 5% decrease the value of stability, but it can increase the value of flow. Moreover, the add of crumb rubber 5% will not influence the VFA value because the value is still remain. Then, the add of crumb rubber 5% will decrease the VIM value than

3% add of crumb rubber. Moreover, the add of crumb rubber 5% on AC-BC will influence the value of MC. Based on the research, it is proven that the add of crumb rubber 5% will decrease the value of MQ than crumb rubber 3%. Then, in terms of VMA value, the add of crumb rubber 5% will not influence the value.

Based on the research result, it can be concluded that  $H_a$  was accepted while  $H_0$  was rejected.  $H_a$  was accepted because there was significant different between crumb rubber for fine aggregate in construction AC-WC and AC-BC. Based on the research result, it can be seen that AC-BC showed the higher value than AC-WC in terms of stability, flow, VFA, VIM, MQ, density and VMA.

Basically, in this research crumb rubber can be added to asphalt concrete, and ulcerate that uses 3% and 5% and the addition of crumb rubber increases (VFA), and because the values (VFA) gave values of inverse (VIM) with the (VFA) always, despite that the stability gave counterproductive. Therefore, it can be concluded that AC-BC mixture with 3% crumb rubber give better strength and durability of asphalt because the add of more crumb rubber will influence the value of strength and durability.

## Conclusions

1. The experimental results indicate that the AC-BC mixture consistently outperforms the AC-WC mixture in terms of stability, flow, and overall durability.
2. Incorporating crumb rubber at 3% and 5% concentrations leads to a significant increase in Voids Filled with Asphalt (VFA) and a corresponding decrease in Voids in the Mixture (VIM). However, this modification shows a counterproductive effect on Marshall stability, particularly at higher concentrations.
3. The study concludes that the AC-BC mixture with 3% crumb rubber provides the optimal balance of mechanical strength and durability. Increasing the crumb rubber content beyond this level negatively impacts the stability and Marshall Quotient (MQ) values, suggesting that lower modification rates are more effective for these specific asphalt grades.

---

## Compliance with ethical standards

### *Disclosure of conflict of interest*

The authors declare that they have no conflict of interest.

---

## References

- [1] American Association of State Highway and Transportation Officials. (1988). *Standard Method of Test for Sieve Analysis of Fine and Coarse Aggregates (AASHTO T 27-88)*. Washington, D.C.
- [2] Bahia, H. U., & Davies, R. (2008). Effect of Crumb Rubber Modifier (CRM) on Performance-Related Properties of Asphalt Binders. *Journal of the Association of Asphalt Paving Technologists*, 63, 414-438.
- [3] Directorate General of Highways. (2010). *Bina Marga Standards for Road Construction*. Jakarta, Indonesia: Ministry of Public Works.
- [4] Lenz, R. W. (2011). *Pavement Design Guide*. Texas Department of Transportation.

**Disclaimer/Publisher's Note:** The statements, opinions, and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of **SJPHRT** and/or the editor(s). **SJPHRT** and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions, or products referred to in the content.