International Journal of GEOMATE, March., 2024 Vol.26, Issue 115, pp.34-43
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2024.115.4195
Geotechnique, Construction Materials and Environment

CHARACTERISTICS OF ASPHALT CONCRETE WEARING COURSE MIX INCORPORATING RECYCLED TIRE RUBBER AS AN ADDITIVE

*Hamkah[1], Zubair Saing[2], Dady Mairuhu[3], and M. Tumpu[4]

[1] Department of Civil Engineering, Ambon State Polytechnic, Indonesia
[2] Department of Civil Engineering, Universitas Muhammadiyah Maluku Utara, Indonesia
[3] Department of Mechanical Engineering, Ambon State Polytechnic, Indonesia
[4] Disaster Management Study Program, Graduate School, Hasanuddin University, Makassar, Indonesia

*Corresponding Author, Received: 22 Oct. 2023, Revised: 15 Jan. 2024, Accepted: 16 Jan. 2024

ABSTRACT: In Indonesia, flexible pavement is the primary form of road infrastructure. It is typically produced using a binder combined with Buton Granular Asphalt (BGA B 5/20) as an additional binder. Tire rubber waste as an additive is considered an option to reduce environmental pollution and promote sustainable procurement strategies. The objective of this study is to evaluate the results of the Marshall characteristic test for an asphalt concrete wearing course (AC-WC) with tire rubber used as an asphalt binder. Three AC-WC mixtures (0%, 5%, and 10%) were subjected to Marshall characteristic tests. The results of the Marshall stability test showed that the untreated AC-WC mixture had a stability of 1312 kg, while the AC-WC mixture with 5% tire rubber had a stability of 1150 kg, indicating a reduction of 12.3%. Similarly, the 10% tire rubber demonstrated a stability of 1100 kg, reflecting a reduction of 16.2%. The Marshall Quotient for the standard AC-WC mixture was 416.9 kg/mm. In contrast, the 5% tire rubber yielded a Quotient of 354 kg/mm, representing a decrease of 15.1%. Additionally, the 10% tire rubber resulted in a Quotient of 289.4 kg/mm, indicating a reduction of 30.1%. The Marshall characteristics VMA, VIM, VFB, and Flow also met the standard criteria for AC-WC. The addition of tire rubber reduced the bearing capacity and resistance to permanent deformation of the AC-WC. However, it was observed that tire rubber waste can be effectively used as an additional binder for asphalt in AC-WC treatment.

Keywords: AC-WC mixture, Tire rubber waste, Marshall characteristic, Additive

1. INTRODUCTION

As roads in Indonesia facilitate over 80-90% of passenger and cargo transportation, the primary focus is developing road transportation infrastructure. The allocation of state funds toward constructing and maintaining new roads aligns with the nation’s developmental goals [1]. The 2023 National Revenue and Expenditure Budget (APBN) includes an initiative by the Ministry of Public Works in the Republic of Indonesia to improve connectivity by constructing 522 km of roadways [2]. However, this practice leads to an increase in the cost of natural aggregates and asphalt. Annually, 600,000 tons of asphalt are imported, which puts pressure on foreign currency availability and aggregate supplies [2,3].

Waste tires present a significant challenge in numerous countries. Tires that have reached the end of their useful life require recycling or proper disposal, including a designated landfill. Tire piles are hazardous to the environment, pose a fire hazard, and provide a breeding ground for mosquitoes [4]. Several strategies for managing or reducing waste tires include incineration, recycling, adding economic value, and pyrolysis, which converts waste tires into fuel [5].

Disposing of used tires has been a primary environmental concern for many years, and finding sustainable solutions to depleting landfills has proven challenging. Before disposal in landfills, tires must undergo shredding. Several innovative methods for tire disposal have been developed over time, offering promising alternatives. These methods include incorporating rubber tires into asphalt mixtures, thermally burning used tires to generate electricity or steam, and utilizing rubber tires to produce various plastic and rubber products [6]. Tire waste disposal presents an opportunity to reduce pollution and support initiatives such as the Clean Development Mechanism (CDM), a globally applicable market-based strategy for reducing CO_2 emissions [7].

Asphalt concrete is a road surface material composed of asphalt and gravel. The mixture is carefully graded, mixed, distributed, and compacted at a precise temperature. The asphalt concrete layer is typically divided into three distinct layers: the asphalt concrete wear layer (AC-WC), the asphalt concrete binder layer (AC-BC), and the asphalt concrete base layer (AC-Base). These layers have varying maximum stone sizes, with 19.0, 25.4, and

37.5 mm dimensions, respectively [8].

Since 1986, the US Department of Transportation and the Federal Highway Administration have researched the integration of old tire rubber into asphalt concrete mixtures. This practice can potentially improve the durability of flexible road surfaces, particularly in challenging weather and traffic conditions [9]. Conventional liquid natural rubber modified by PVLNR is used explicitly as an asphalt modification material [10]. According to ASTM D-6270-08, used tires can take various forms, such as tire-derived aggregates (TDA), tire sidewalls, and intact used tires used in civil engineering applications [11]. Kurniati's research [12] found that when using tire rubber in the AC mixture without RBA B 5/20 Buton granular asphalt, the optimum asphalt content tends to be higher than when using RBA B 5/20. The optimal asphalt content for mixtures that use tire rubber is 7.40%, while the optimal asphalt content for mixtures without tire rubber is 7.10%. Tire rubber in asphalt concrete mixtures can increase resistance to persistent wrinkle deformation.

Compared to regular asphalt concrete without any supplementary ingredients, asphalt concrete incorporating powdered elements such as old tire rubber exhibits improved resistance to extreme temperatures and stresses caused by vehicular traffic. Additionally, the inclusion of additives in asphalt concrete mixtures can enhance shear strength, particularly under high-temperature conditions, thereby mitigating potential pavement damage [13]. Research suggests that adding latex and tire waste rubber (STR) as additives in asphalt concrete can alter its properties. Specifically, it can decrease the asphalt's penetration value and specific gravity while increasing the softening point value. However, the effect on strength values can vary and produce mixed results. Including latex generally does not significantly affect the durability rating, while adding STR may diminish durability [14]. In his research on the existence of limestone in the mix, Djakfar et al. [15] found that it also improved the performance of cold paving hot mix asphalt (CPHMA). Based on the results, it can be concluded that given some treatments, the asphalt mixture can be used as patching material and structural layer material, particularly for low to medium-traffic rural roads.

The use of CRM (Crumb Rubber Modifier) derived from old motorcycle tires has been found to improve the stability of both AC-WC (Asphalt Concrete Wear Course) and ACB (Asphalt Concrete Binder). Among various CRM asphalt mixtures, the combination containing 1% CRM from motorcycle tires is the most favorable based on stability, flowability, and overall Marshall performance. It is important to note that including CRM from used motorcycle tires improved the flowability of the AC-WC mixture. However, adding 1.5% or 3%, ACB had the opposite effect. To ensure that the Marshall quotient values fall within the recommended standards [16], it is advisable not to exceed 1.5% CRM from old motorcycle tires or 3% ACB in the AC-WC mixture. BGA B 5/20 can be used as a filler in hot asphalt mixes, contributing to producing high-quality asphalt mixtures. This natural asphalt product is readily usable and characterized by high quality, with the asphalt being absorbed onto the granules' surface. The advantage of using BGA B 5/20 in hot mix asphalt is its ability to enhance penetration and reduce the cost of obtaining oil asphalt by up to 20% of the total asphalt cement required. The products are in different packaging sizes: net 25 kg, 50 kg, and 1 ton. B 5/20 bituminous asphalt comprises fine particles that pass through filter No. 8 (maximum size 2,296 mm) and contain approximately 20% asphalt [17].

This research aims to evaluate and compare the results of Marshall property tests conducted on asphalt concrete wearing course (AC-WC) mixtures. Compared to conventional AC-WC mixtures without additional components, the AC-WC mixes incorporate recycled tire rubber as an asphalt binder. Analyzing Marshall properties involves determining optimal asphalt content parameters to meet Marshall property specifications. These specifications include voids in the mix (VIM), voids in the mineral aggregate (VMA), voids filled with bitumen (VFB), flowability, Marshall stability, and Marshall quotient (MQ). These specifications include voids in the mix (VIM), voids in the mineral aggregate (VMA), voids filled with bitumen (VFB), flowability, Marshall stability, and Marshall quotient (MQ). These specifications include voids in the mix (VIM), voids in the mineral aggregate (VMA), voids filled with bitumen (VFB), flowability, Marshall stability, and Marshall quotient (MQ).

2. RESEARCH SIGNIFICANCE

Research into the Marshall characteristics of AC-WC, which involves adding used rubber tires to road pavement mixtures, has led to investigations into the limits of rubber tires that can be used. Using rubber tires in asphalt concrete mixes promotes waste reduction and reduces landfill usage. The findings of this research will aid in developing specifications, particularly in determining optimal asphalt content limits. The 2018 Bina Marga Specifications [8] have undergone three revisions in the last four years to become a reference for determining the AC-WC asphalt work mix design. These specifications also regulate the properties of other asphalt mixtures used for road pavement.

3. MATERIAL AND METHODS

The investigation employed a coarse aggregate of 1-2 cm and a fine aggregate of 0.5 max. Size, tire rubber waste crushed 2-3 cm, Buton granular asphalt (BGA B-5/20), and bitumen asphalt (Petroleum pen. 60/70) as materials. Visual representations of these materials are shown in Figs. 1 to 3.

Fig.1 Coarse aggregate 1-2 cm (A), Fine aggregate 0.5 cm max. Size. (B)

Fig.2 Tire rubber waste 2-3 cm

Fig. 3 Buton granular asphalt (BGA B 5/20) [18]

The research methodology is based on experimental tests conducted in the laboratory of Ambon State Polytechnic. Material properties were tested, including specific gravity, water absorption capacity, abrasion using a Los Angeles Machine, adhesion between aggregate and asphalt, coarse aggregate evenness index, fine aggregate specific gravity, filler material and used tire rubber, and asphalt testing.

The argument for using tire rubber content in asphalt was based on ASTM D6270-08 [16], which recommends a maximum of 1.5% CRM of used motorcycle tires to avoid Marshall quotient values falling outside the recommended standards.

The study found that the combination containing 1% CRM from motorcycle tires had the most favorable properties, including stability, flowability, and overall Marshall performance. It is important to note that subjective evaluations were excluded from this analysis.

If the asphalt cement content (Petroleum) in the most considerable mixture weight is selected to be 7.0%, excluding the asphalt content in BRA/BGA B 5/20 Butonic granular asphalt, which is approximately 20%, then the total asphalt content in the weight of the AC-WC mixture is a maximum of around 9%. Therefore, 1% CRM added to the weight of the mixture accounts for 1/9 or 11% of the weight of the asphalt content (not the weight of the mixture).

The tests used adhere to various standards, including the Indonesian National Standards SNI 1969:2008 for specific gravity tests [19], SNI 2417:2008 for Los Angeles Machine abrasion tests [20], SNI 03-2439-1991 for aggregate and asphalt adhesion tests [21], and SNI 06-2456-1991 for asphalt penetration testing [22].

The design of asphalt concrete mixtures follows an absolute density approach per the guidelines provided by the Directorate General of Highways, Ministry of Public Works of the Republic of Indonesia [23].

Table 1 Marshall characteristic samples preparation

Test	Mixture type	Asphalt content (%)	The number of samples	
			Number	Total
Marshall test	AC standard	5.5	3	12
		6.0	3	
		6.5	3	
		7.0	3	
	$AC_{\text{tire rubber 5\%}}$	5.5	3	12
		6.0	3	
		6.5	3	
		7.0	3	
	$AC_{\text{tire rubber 10\%}}$	5.5	3	12
		6.0	3	
		6.5	3	
		7.0	3	
Total number of samples			36	

Particle size distribution curves of the combined aggregate gradation between coarse aggregate and fine aggregate, respectively, is shown in Fig. 4 [24]. A total of 36 samples were prepared for the Marshall characteristics test. The samples consisted of three AC-WC mixtures, each with four different asphalt contents: 5.5, 6.0, 6.5, and 7.0%. Table 1 presents the details.

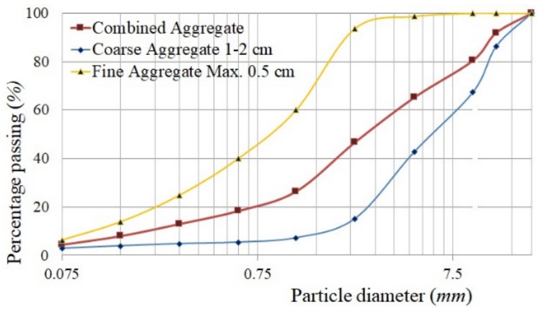

Fig. 4 Particle size distribution curves

The four differences in asphalt content discussed above are derived from Kurniati's research [12]. Based on the research, the ideal amount of asphalt in the AC mixture made with RBA B 5/20 Buton granular asphalt was 7.10%, but the ideal amount in the mixture made using tire rubber was 7.40%.

4. RESULTS AND DISCUSSIONS

Tests were conducted to evaluate the physical properties of materials used in the study, including coarse aggregate, fine aggregate, tire rubber waste, and Buton granular asphalt (BGA B 5/20). The tire rubber waste was sourced from a motorcycle repair shop in Ambon, Maluku, Indonesia. The aggregate gradation selected met the specifications for highway-grade asphalt concrete mixtures. Refer to Tables 2 to 4 for more information on the physical properties of Buton granular asphalt, fine aggregate, coarse aggregate, and the chemical composition of tire rubber waste. Table 2 [25] provides a detailed breakdown of the chemical composition of used tire rubber, including 25% natural rubber, 35% carbon black rubber content, 15% butadiene rubber content, and 5% butyl rubber content.

Table 2 Chemical content of tire rubber waste [25]

No.	Tests	Value
1.	Levels of natural rubber	25%
2.	Levels of butadiene rubber	15%
3.	Levels of butyl rubber	5%
4.	Rubber carbon black	35%
5.	Levels of ZnO	4%
6.	Levels oil neptheniclaromatic	4%
7.	Levels of dirt/dust/kaolin/calcium	12%
8.	Specific gravity	0.971

Table 3 outlines the physical properties of crushed stone. The coarse aggregate has a specific gravity of 2.58, meeting the minimum requirement of 2.50 [19]. Additionally, the water absorption capacity of the coarse aggregate is 1.44%, which falls within the maximum allowable limit of 3.0% [19].

The abrasion hardness test results obtained using the Los Angeles Machine indicate a value of 21.24%, which meets the maximum requirement of 40% [20]. Additionally, the adhesion between the aggregate and asphalt is measured at 97.5%, exceeding the minimum requirement of 95% [21].

Finally, the fragility index of the coarse aggregate is determined to be 23.26%, which complies with the maximum allowable limit of 25%.

Table 4 presents the physical properties of tire rubber waste measuring 2-3 cm and fine aggregate with a maximum size of 0.5 cm. The specific gravity of the fine aggregate meets the minimum requirement of 2.5, with a recorded value of 2.56.

The water absorption capacity of the fine aggregate is also within the maximum requirement of 3.0, with a measured value of 2.62%. The specific gravity of the tire rubber waste is 0.971.

The asphalt used is derived from petroleum and has a penetration level 60/70. Based on the test results, the asphalt exhibits several vital properties: Penetration:

The penetration test yielded a value of 65.85 mm, falling within the specified range of 60-79 mm; Softening Point: The asphalt's softening point was determined to be 48.25°C, conforming to the specifications of 48-58°C; Flash Point: The flash point of the asphalt was measured at 332°C, exceeding the minimum requirement of 200°C.

The fire point was determined to be 339°C, and the specific gravity was found to be 1.035, meeting the minimum requirement of 1.0. These test results, detailed in Table 5 [1], provide valuable information about the properties of the asphalt and its suitability for use in the asphalt mixture. BGA B 5/20 is a product from Buton Island, Indonesia.

It functions as an additional binder in hot mix asphalt, aiming to increase the performance and durability of asphalt concrete against heavy loads and extreme weather conditions.

Various domestic and international studies demonstrated that the stability value and soft point of asphalt concrete mixtures were increased by incorporating BGA into asphalt concrete mixtures. This typically results in stability value increases of 20% to 30%.

Table 3 Physical properties of crushed stone [19]

No.	Tests	Unit	Value	Specification		Standard
				Min.	Max.	
1.	Bulk specific gravity	-	2.58	2.5	-	SNI 1969: 2008
2.	Absorption of water	%	1.44	-	3.0	
3.	Abrasion with Los Angeles Machine	%	21.24	-	40.0	SNI 2417: 2008
4.	Adhesive aggregate and asphalt	%	97.5	95.0	-	SNI 03-2439-1991
5.	Flakiness index of coarse aggregate	%	23.26	-	25.0	SNI-M-25-1991-03

Table 4 Physical properties of tire rubber waste and fine aggregate

No.	Tests	unit	Value	Specification		Standard
				Min.	Max.	
1.	Bulk specific gravity (fine aggregate)	-	2.56	2.5	-	SNI 1969: 2008
2.	Absorption of water (fine aggregate)	%	2.60	-	3.0	
3.	Specific gravity (tire rubber waste)	-	0.971	-	-	SNI-06-2441-1991

Table 5 Asphalt test results [1]

No.	Tests	Unit	Result	Specification		Standard
				Min.	Max.	
1.	Penetration,25°C,100gr, 5sec.	DMM	65.85	60	79	SNI 06-2456-1991
2.	Softening point of asphalt	°C	48.25	48	58	SNI 06-2434-1991
3.	The flash point of asphalt	°C	332	200	-	SNI 06-2433-1991
4.	Fire point of asphalt	°C	339	-	-	SNI 06-2433-1991
5.	Ductility, 25°C	cm	>100	100	-	SNI 06-2432-1991
6.	Specific gravity of asphalt	-	1.035	1.0	-	SNI 06-2441-1991

BGA is a valuable material for enhancing the quality of asphalt pavement. Asbuton is a precursor to BGA, comprising around 20-30% pure bitumen and 70-80% mineral limestone. In asphalt, the bitumen in Asbuton acts as a binder, similar to oil asphalt, while the minerals serve as fillers and fine aggregates, following the mix's graduation requirements.

BGA is easy to use and effective, especially when working in small spaces with mixing equipment. In a pug mill, the result can be combined with bitumen and aggregate without the need for extra equipment or mixers. It comes from the Buton source and has a high softening point and low penetration value, which effectively increases the longevity of road pavements.

After processing Asbuton with premium asphalt granules that have a maximum grain size of 2.36 mm, BGA is the result. One of PT. Putindo Bintech's granular asphalt products is BGA B 5/20, which has the specifications shown in Table 6.

Table 6 Specifications of BGA B 5/20 [26]

Specification	Range
Bitumen content; %	24 – 27
Water content; %	Max. 2
Bitumen's penetration; 0,1 mm	< 10

4.1 AC-WC$_{Asb.}$

The test results for three types of AC-WC mixtures, namely AC-WC Standard, AC-WC with 5% tire rubber, and AC-WC with 10% tire rubber, were analyzed based on their ability to fulfill Marshall characteristics. The asphalt content varied between 5.5% and 7.0%, with an addition of 0.5%.

4.1.1 AC-WC$_{STANDARD}$

The Void in Mineral Aggregate (VMA) and Void Filled with Bitumen (VFB) meet the minimum specification of 15% and 65% at an asphalt content of 5.5% to 7.0%. The Void in the Mixture (VIM) meets the specifications of 3.0% - 5.0% at an asphalt content of 5.63% to 6.65%. However, at an asphalt content of 7.0%, the VIM is only 2.68%, less than the minimum requirement of 3%. At an asphalt content of 5.5%, the value is 5.36%, higher than the maximum specification. The stability of AC-WC$_{Standard}$ meets the minimum specification of 1000 kg at an asphalt content of 5.5% to 6.90%. However, at an asphalt content of 7.0%, the stability is only 938 kg, less than the minimum specification. Similarly, the flow of AC-WC$_{Standard}$ meets the specifications of 2.0 - 4.0 mm at an asphalt content of 5.5% to 6.71%. Still, at an asphalt content of 7.0%, the flow value is 4.24 mm, higher than the maximum specification of 4.0 mm.

The Marshall Quotient (MQ) value meets the minimum specification of 250 kg/mm at an asphalt content of 5.5% to 6.86%. However, at an asphalt content of 7.0%, the MQ value is only 221.2 kg/mm, less than the minimum specification.

Table 7 Marshall test analysis results for AC-WC$_{Standard}$.

Characteristic of mixture	Bitumen/asphalt content (%)				Specification AC-WC Asb. [23]
	5.5	6.0	6.5	7.0	
VMA (%)	17,65	16,98	17,0	17,68	Min. 15%
VIM (%)	5,36	3,98	3,14	2,68	3.0 - 5.0 %
VFB (%)	68,04	72,64	76,29	78,65	Min. 65%
Stability (kg)	1275	1340	1241	938	Min. 1,000 kg
Flow (mm)	2,36	2,96	3,82	4,24	2.0 – 4.0 mm
MQ (kg/mm)	540,3	452,7	324,9	221,2	Min. 250 kg/mm

Figs. 5 and 6 present stability and flow data for three types of AC-WC mixtures at four variations in asphalt content. The analysis of the fulfillment of asphalt content and OAC is shown in Fig.7. Table 8 presents the test results for the AC-WC$_{Tire\text{-}rubber}$ 5% and AC-WC$_{Tire\text{-}rubber}$ 10% mixture. The analysis of the fulfillment of asphalt content and OAC is shown in Figs. 8 and 9.

4.1.2 AC-WC$_{Tire\text{-}rubber}$

Table 8 presents Marshall's test analysis for AC-WC$_{Tire\text{-}rubber\ 5\%}$ and AC-WC$_{Tire\text{-}rubber\ 10\%}$. Data on Void in mineral aggregate (VMA) and Void filled with bitumen (VFB) for AC-WC$_{Tire\ rubber\ 5\%}$ met the minimum requirements of 15% and 65% at asphalt content of 5.5% to 7.0%. Voids in the mixture (VIM) meet specifications of 3.0% - 5.0% at asphalt content of 5.5% to 6.46%, VIM for asphalt content of 6.5 and 7.0% each is only 2.94 % and 2.58% less than the minimum specification of 3%.

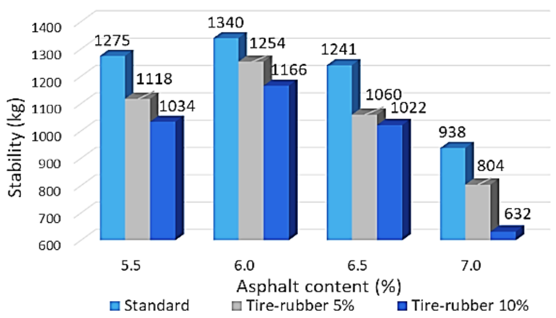

Fig. 5 Relationship Stability with asphalt content

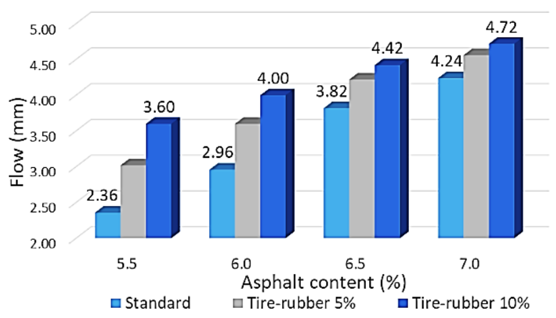

Fig. 6 Relationship flow with asphalt content

The marshall stability meets the minimum specifications of 1000 kg at an asphalt content of 5.5% to 6.62%. The marshall stability of AC-WC$_{Tire\ rubber\ 5\%}$ at an asphalt content of 7.0% is only 804 kg, less than the minimum specification. Flow meets specifications 2.0 - 4.0 mm at asphalt content 5.5% to 6.32%, Flow AC-WC$_{Tire\text{-}rubber\ 5\%}$ at asphalt content 6.5% and 7.0% each with a value of 4, 22 mm and 4.56 mm higher than the maximum specification of 4.0 mm. Marshall Quotient (MQ) meets the minimum specification of 250 kg/mm at an asphalt content of 5.5% to 6.51%. MQ at asphalt content of 7.0% is only 176.3 kg/mm, less than the minimum specification. Table 8 also presents data on Void in mineral aggregate and Void filled with bitumen for AC-WC$_{Tire\ rubber\ 10\%}$, respectively, meeting the minimum requirements of 15% and 65% at asphalt content of 5.5% to 7.0%. Voids in the mixture (VIM) meet specifications of 3.0% - 5.0% at asphalt content 5.5% to 6.22%, VIM for asphalt content 6.5 and 7.0% each is only 2.57 % and 2.14% less than the minimum specification of 3%.

The Marshall stability meets the minimum specification of 1000 kg at an asphalt content of 5.5% to 6.53%. The Marshall stability of AC-WC$_{Tire\ rubber\ 10\%}$ at an asphalt content of 7.0% is only 632 kg, less than the minimum specification. Flow meets specifications 2.0 - 4.0 mm at asphalt content 5.5% to 6.0%, Flow AC-WC$_{Tire\text{-}rubber\ 10\%}$ at asphalt content 6.5% and 7.0% each with a value of 4, 42 mm and 4.72 mm, higher than the maximum specification of 4.0 mm. Marshall Quotient meets the minimum specification of 250 kg/mm at an asphalt content of 5.5% to 6.34%, MQ at an asphalt content of 6.5% and 7.0% is only 232.1 kg/mm and 133.9 kg/mm respectively, less than minimum specification.

Fig. 5 and Fig. 6, respectively, present stability and flow data from test results for three types of AC-WC mixtures at four variations in asphalt content. Table 7 presents the test results for the standard mixture type and the specifications that must be met [23]. An analysis of the fulfillment of asphalt content and OAC is shown in Fig. 7.

Table 8 presents the test results for the AC-WC$_{Tire\text{-}rubber\ 5\%}$, and AC-WCTire-rubber 10% mixture; analysis of the fulfillment of asphalt content and OAC is shown in Fig. 8 and Fig. 9.

Table 8 Marshall test analysis results for AC-WC$_{\text{Tire-rubber 5\%}}$ and AC-WC$_{\text{Tire-rubber 10\%}}$

Characteristic of mixture	AC-WC$_{\text{Tire rubber 5\%}}$ Asphalt content (%)				AC-WC$_{\text{Tire rubber 10\%}}$ Asphalt content (%)				Specification AC-WC Asb. [23]
	5.5	6.0	6.5	7.0	5.5	6.0	6.5	7.0	
VMA (%)	17,25	16,87	16,82	17,31	16,86	15,94	15,90	16,78	Min. 15%
VIM (%)	4,90	3,77	2,94	2,58	4,52	3,35	2,57	2,14	3.0 - 5.0%
VFB (%)	69,12	75,64	82,29	83,25	70,43	78,66	82,48	85,76	Min. 65%
Stability (kg)	1118	1254	1060	804	1034	1166	1012	632	Min. 1,000 kg
Flow (mm)	3,02	3,60	4,22	4,56	3,60	4,00	4,42	4,72	2.0 – 4.0 mm
MQ (kg/mm)	370,2	348,3	251,2	176,3	287,2	291,5	232,1	133,9	Min. 250 kg/mm

4.1.3 AC-WC mixture on optimum asphalt content

The determination of the optimum asphalt content (OAC) for each mixture, including AC-WC$_{\text{Standard}}$, AC-WC$_{\text{Tire-rubber 5\%}}$, and AC-WC$_{\text{Tire-rubber 10\%}}$, is illustrated in Fig. 7, Fig. 8, and Fig. 9, respectively. AC-WC$_{\text{Standard}}$ meets six marshall characteristics at a minimum asphalt content of 5.63% to 6.65% maximum, as shown in Figure 6, and the AC-WC$_{\text{Standard}}$ optimum asphalt content of 6.14% is determined from the middle value between the maximum and minimum asphalt content. AC-WC$_{\text{Tire-rubber 5\%}}$ fulfills 6 Marshall characteristics at a minimum asphalt content of 5.5% to a maximum of 6.32%, as shown in Fig. 7, and the standard AC-WC optimum asphalt content of 5.87%. AC-WC$_{\text{Tire-rubber 10\%}}$ fulfills 6 Marshall characteristics at a minimum asphalt content of 5.5% to 6.0% maximum, as shown in Fig. 8, with an optimum of 5.75%. Indeed, the optimum asphalt content value for the AC-WC$_{\text{Standard}}$ mixture is 6.14%, which is higher than the optimum asphalt content for both the AC-WC$_{\text{Tire-rubber 5\%}}$ mixture (5.87%) and the AC-WC$_{\text{Tire-rubber 10\%}}$ mixture (5.75%). The AC-WC mixture without tire rubber exhibited a higher stability of 1,312 kg.

In contrast, the AC-WC mixture with 5% tire rubber had a stability of 1,150 kg, and the AC-WC mixture with 10% tire rubber had a stability of 1,100 kg. The AC-WC$_{\text{Standard}}$ mixture had a flow value of 3.2 mm, the AC-WC$_{\text{Tire-rubber 5\%}}$ mixture had a flow value of 3.5 mm, and the AC-WC$_{\text{Tire-rubber 10\%}}$ mixture had a flow value of 3.8 mm.

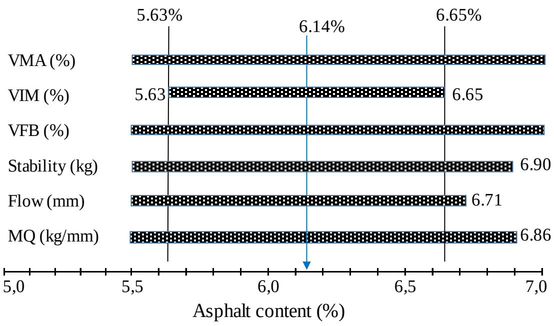

Fig.7 OAC of AC-WC$_{\text{Standard}}$ mixture

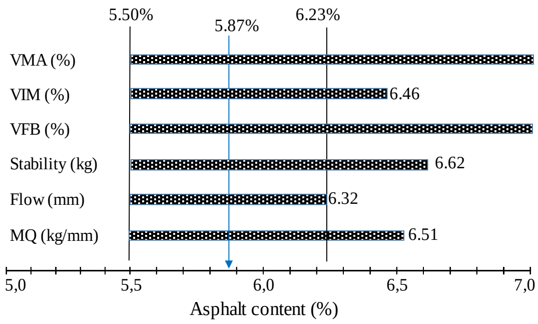

Fig.8 OAC of AC-WC$_{\text{Tire-rubber 5\%}}$ mixture

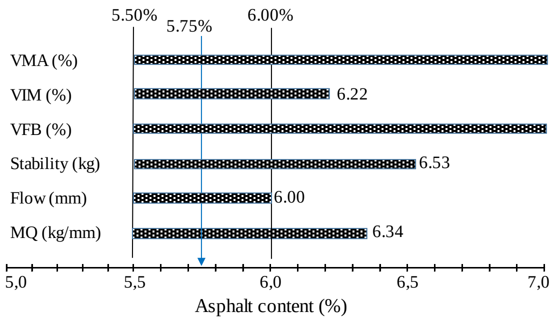

Fig.9 OAC of AC-WC$_{\text{Tire-rubber 10\%}}$ mixture

4.2 Discussions

Developing sustainable asphalt concrete using waste materials as substitutes for natural resources is environmentally beneficial, especially when dealing with non-biodegradable waste like tire rubber waste [27]. The outcome of the tests carried out on modified asphalt mixtures with both used rubber and waste plastic can be advised that adding them leads to an apparent increase in Marshall's stability [28].

Given the continuous increase in discarded tires each year, using tire rubber waste in asphalt concrete mixtures holds significant potential. It is promising for implementation not only in Indonesia but also in other developing countries. Incorporating used tire waste into asphalt concrete mixtures is an alternative to mitigating environmental pollution. It aligns with the objectives of the Clean Development Mechanism (CDM) program. CDM is a crucial international market-based mechanism designed to reduce carbon emissions, making it an important global initiative for addressing climate change [7].

The results of the interpolation analysis of Fig. 7, Fig. 8, and Fig. 9 obtained the optimum asphalt content for three types of mixtures: AC-$WC_{Standard}$ mixture is 6.14%, AC-$WC_{Tire\text{-}rubber}$ 5% mixture is 5.87%, and AC-$WC_{Tire\text{-}rubber}$ 10% mixture is 5.75%.

This finding aligns with previous research by Kurniati [12] and Novianto [29]. Using tire rubber in the Asphalt Concrete (AC) mixture without Buton granular asphalt RBA B 5/20, the optimum asphalt content tends to be higher than when using Buton granular asphalt. Specifically, the optimal asphalt content for mixtures that use tire rubber is 7.40%, while the optimal asphalt content for mixtures without tire rubber is 7.10%.

Furthermore, the addition of 5% tire rubber to the AC-WC mixture resulted in the highest water resistance (93.24%) compared to the 10% addition (91.12%) and the AC-WC mixture without tire rubber (91.54%). However, it's important to note that the AC-WC mixture with 5% and 10% tire rubber waste exhibited lower tensile strength than the AC-WC mixture without tire rubber (AC-$WC_{Standard}$). Additionally, including used rubber tires in asphalt concrete mixtures, up to approximately 3%, enhances performance, particularly at temperatures exceeding 30°C [29]. This suggests that utilizing used tire rubber waste as an additive in asphalt concrete is well-suited for road pavements in hot climate conditions [10].

Interpolation analysis of Fig. 7, Fig. 8, and Fig. 9 obtained Voids in Mixture (VIM) values at the optimum asphalt content as follows: AC-$WC_{Standard}$ mixture is 3.74%, AC-$WC_{Tire\text{-}rubber}$ 5% mixture is 4.06%, and AC-$WC_{Tire\text{-}rubber}$ 10% mixture is 3.94%. Differences in asphalt content and density values cause variations in VIM values. Maintaining the VIM value within a specific range is essential [2]. Recommended range for VIM in AC-$WC_{Asb.}$ Mixtures are between 3.0% and 5.0% [7,30]. Mixtures falling into this range are not susceptible to melting, flowing, and plastic deformation.

In the same analysis, the stability value at the optimum asphalt content for the AC-$WC_{Standard}$ mixture is 1,312 kg, while it is 1,150 kg for the AC-$WC_{Tire\text{-}rubber}$ 5% mixture and 1,100 kg for the AC-$WC_{Tire\text{-}rubber}$ 10% mixture. Using 5% and 10% tire rubber reduces the stability value of the AC-$WC_{Standard}$ mixture by 12,3% and 16,2%, respectively. Crushed stone aggregate has better abrasion resistance and hardness than used rubber tires. In addition, used rubber tires have a rounded shape, break easily, and do not provide good aggregate interlocking, which results in lower stability for the AC-$WC_{Tire\text{-}rubber}$ 5% mixture compared to the AC-$WC_{Standard}$. Requirements for stability values in AC-$WC_{Asb.}$ Mixtures set a minimum of 1,000 kg [8,30]. Three different types of asphalt concrete mixes meet the specified stability requirements for AC-WC mixes.

The results of the Marshall flow test for the optimum asphalt content are as follows: AC-$WC_{Standard}$ mixture: Marshall flow value is 3.20 mm, AC-$WC_{Tire\text{-}rubber\ 5\%}$ mixture: Marshall flow value is 3.5 mm, and AC-$WC_{Tire\text{-}rubber\ 10\%}$ mixture: Marshall flow value is 3.8 mm. Tire rubber waste differs from crushed stone aggregate in that it is not porous and tends to absorb asphalt, while crushed stone aggregate does not. The specification for the flow value in AC-$WC_{Asb.}$ Mixtures set a minimum requirement of 2.0 mm [8,30]. All three mixtures meet this minimum flow value requirement.

The Marshall Quotient values for these mixtures are as follows: AC-$WC_{Standard}$ mixture: Marshall Quotient is 416.9 kg/mm, AC-$WC_{Tire\text{-}rubber\ 5\%}$ mixture: Marshall Quotient is 354.0 kg/mm, and AC-$WC_{Tire\text{-}rubber\ 10\%}$ mixture: Marshall Quotient is 289.4 kg/mm. The AC-$WC_{Standard}$ mixture is more rigid than the AC-$WC_{Tire\text{-}rubber\ 5\%}$ mixture but still complies with the Marshall Quotient value specifications for AC-WC (minimum 250 kg/mm) [8,23]. Based on the characteristics observed in the Marshall test, using tire rubber waste as an additional asphalt binder in asphalt concrete is acceptable, particularly for specialized mixtures used in road surface layers.

5. CONCLUSION

Marshall characteristics of AC-WC mixtures without tire rubbers, such as Void in Mineral Aggregate, Voids in Mixture, Stability, and Marshall Quotient, have higher values than AC-WC mixtures using tire rubbers. The differences in characteristics are due to the combination of tire rubber waste, which influences the various properties of the asphalt mixture. The addition of tire rubber waste of up to 10% to the weight of asphalt resulted in a reduction in the optimum, maximum, and minimum asphalt content values in the AC-WC mixture using BGA B 5/20. Further research on tire rubber waste as an alternative material to replace asphalt concrete in other flexible pavement layer mixtures, including Hot Rolled Sheet, AC-BC, and AC-Base.

6. ACKNOWLEDGMENTS

We want to thank Ambon State Polytechnic for its support of this research. Thank you also to all parties who have helped carry out this research. We appreciate the reviewers who provided suggestions and comments to improve this article.

7. REFERENCES

[1] Sugiyanto G., Marshall Test Characteristics of Asphalt Concrete Mixture with Scrapped Tire Rubber as A Fine Aggregate, UTM Press Publisher, Technology Journal (Sciences & Engineering), Vol. 79, No. 2, 2017, pp. 55–64.

[2] Republic of Indonesia, Financial Notes and Draft State Revenue and Expenditure Budget for FY 2023, Book 3, Collection of Work Plans & Budgets for State Ministries/Institutions (RKA-K/L), 2023.

[3] Sjahdanulirwan M., Utilization of Technology in Increasing the Role of Civil Engineering. Proceedings of the National Civil Engineering Seminar, Maranatha Christian University, Bandung, West Java, Indonesia, 2007, pp. 6-9.

[4] Tantala M.W., Lepore J.A., and Zandi I., Quasi Elastic Behavior of Rubber Included Concrete, Proceedings 12th International Conference on Solid Waste Technology and Management, Philadelphia, 1996.

[5] Ghina D.A., Utilization of Waste Tires as an Alternative Additional Material in Aggregate Concrete, Rakyat Merdeka, The Political News Leader, 2022.

[6] Naik T.R., and Siddique R., Properties of Concrete Containing Scrap Tire Rubber-An Overview, Report No. CBU-2002-06 REP-459, February 2002, Department of Civil Engineering and Mechanics, College of Engineering and Applied Science, The University of Wisconsin-Milwaukee, 2002.

[7] Cheng C-C., Pouffary S., Svenningsen N., and Callaway J.M., The Kyoto Protocol, The Clean Development Mechanism and the Building and Construction Sector-A, Report for The UNEP Sustainable Buildings and Construction Initiative, United Nations Environment Programme (UNEP), Paris, France, 2008.

[8] Ministry of Public Works Republic of Indonesia, Hot Asphalt Mix, General Specifications for Roads and Bridges, Section 6.5, Jakarta, 2020.

[9] American Associate of State Highway and Transportation Officials, Standard Specifications for Transportation Materials of Sampling & Testing Part 2, Washington DC, 1982.

[10] Irfan, Subagio B.S., Hariyadi E.S., and Maha I., Performance Evaluation of Pre-Vulcanized Liquid Natural Rubber (PVLNR) In Hot Mix Asphaltic Concrete, International Journal of GEOMATE, Vol. 20, Issue 78, 2021, pp.107-114.

[11] ASTM D6270-08, Standard Practice for Use of Scrap Tires in Civil Engineering Applications, ASTM International, West Conshohocken, PA, 2012.

[12] Kurniati N., Characteristics of Asphalt Concrete Mixes with Used Tires Substituted as Aggregate, Civil Engineering: Transportation Engineering, Magister Program, Bandung Institute of Technology, West Java, Indonesia, 2005.

[13] Aprina W., and Silfiani, Marshall Characteristics and Evaluation of Optimum Asphalt Content of Hot Rolled Sheet Mixtures with Used Tire Powder as Additive Material. Undergraduate Program, Civil Engineering Department, Bandung Institute of Technology, West Java, Indonesia, 2005.

[14] Kusumawati A., and Siswosoebrotho B.I., Performance of Asphalt Concrete Mixtures Using Used Tire Powder as an Asphalt Additive. Proceeding of the 4th Inter-University of Transportation Study Forum Symposium, Bali: Udayana University, Indonesia, 2001.

[15] Djakfar L., Bowoputro H., Akbariawan R., and Fadiansyah R., The Effect of Limestone and Reheating Temperature on Cold Paving Hot Mix Asphalt, International Journal of GEOMATE, 2017, Vol. 12, Issue 29, 2017, pp. 212-219.

[16] Iriansyah A.S., and Sjahdanulirwan M., The Utilizing of Natural and Used Rubber for Improving Asphalt Pavement Performance in Indonesia, Proceeding of the Second International Conference on Road and Airfield Pavement Technology, Singapore, 1995.

[17] Siswanto H., Supriyanto B., Pranoto, Chandra P. R., and Hakim A.R., Marshall Properties of Asphalt Concrete Using Crumb Rubber Modified of Motorcycle Tire Waste, AIP Conference Proceedings 1887, 020039, 2017.

[18] Aspal Berjaya, Buton Granulated Asphalt, 2023. Access on https://aspaljakarta.com/asbuton/

[19] Indonesian Standard for Test, SNI-1969:2008, How to Test Specific Gravity and Water Absorption of Coarse Aggregate. National Standardization Agency, Jakarta, 2008.

[20] Indonesian Standard for Test, SNI-2417:2008, How to Test Aggregate Hardness with a Los Angeles Abrasion Machine, National Standardization Agency, Jakarta, 2008.

[21] Indonesian Standard for Test, SNI-03-2439-1991, Method for Testing Aggregate Adhesion to Asphalt, National Standardization Agency, Jakarta, 1991.

[22] Indonesian Standard for Test, SNI-06-2456-1991, Asphalt Penetration Testing Method, National Standardization Agency, Jakarta, 1991.

[23] Directorate General of Highways, Guidelines for Planning Hot Mix Asphalt with Absolute Density Approach, No. 025/T/BM/1999,

Jakarta: Directorate General of Highways, 1999.
[24] Directorate General of Highways, Asphalt Concrete Coating Instructions for Highways/SKBI 2.4-26.1987 UDC: 625.75(02), Jakarta: Public Works Publishing Agency Foundation, Ministry of Public Works Republic of Indonesia, 1987.
[25] Rumahorbo D., and Manurung B., Laboratory Performance of Hot Mix Asphalt Concrete Containing Used Tire Powder, Undergraduate Program, Civil Engineering Department, Bandung Institute of Technology, West Java, Indonesia, 2001.
[26] Buton Asphalt Indonesia, Buton Rock Asphalt from PT. Putindo Bintech, 2023.
[27] Ganesan N., Raj J.B., and Shashikala A.P., Flexural Fatigue Behavior of Self-Compacting Rubberized Concrete, Construction and Building Materials, Vol. 44, 2013, pp. 7-14.
[28] Aladday F., Awad A., and Alsaleh F., Lowcost Pavement by Using Solid Waste, Recycle Aggregates, Crumb Rubber, and Waste Plastic for Rural Road, International Journal of GEOMATE, Vol. 20, Issue 77, pp.18-23.
[29] Novianto D., and Subagyo U., Study of Indirect Tensile Strength Testing of Asphalt Concrete Mixes Containing Used Tire Powder, Undergraduate Program, Civil Engineering Department, Bandung Institute of Technology, West Java, Indonesia, 2001.
[30] Ministry of Public Works, Building Construction Guidelines No. 001-03/BM/2006. Use of Asbuton, Book 3, Hot Asphalt Mixture with Processed Asbuton, Jakarta: Ministry of Public Works Indonesia, 2006.