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Laboratory Testing Performance of Hot Mix Asphalt Containing Waste Materials

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Abstract. Road conditions are frequently subjected to damage that outlasts the road's design life. One of these is due to the material's mechanical capability, which is insufficient to withstand traffic loads and weather conditions. The incorporation of plastic and tire waste into Hot Mix Asphalt is one of the efforts to improve the material's mechanical quality (HMA). In addition to reducing the asphalt concentration in the mixture, the percentage of plastic and tire debris reduces the environmental impact. The use of plastic and tire waste in HMA can aid in the creation of green roads. The goal of this research is to see how plastic and tire waste affect HMA performance in Marshall testing. The research was conducted by making test samples with variations of waste materials percentage. Then, the Marshall test was carried out. Analysis of test results includes volumetric properties and Marshall characteristics. The test results showed that the addition of plastic and tire waste was able to improve the performance of the HMA mixture. However, the performance of the HMA mixture will decrease due to the influence of water soaking the HMA mixture. The addition of the optimum waste was obtained by 2.5% at the optimum asphalt content of 5.5%.

Keywords: Hot Mix Asphalt, Marshall, Plastic, Tire, Waste.

INTRODUCTION

Flexible pavements are more prone to damage before the road's design life is reached [1,2]. Overload, weather conditions, material quality, and field implementation methods were among the factors that caused damage [3]. Deformation, cracking, and raveling are common damages in Hot Mix Asphalt (HMA) [4,5,6]. Damage investigation is required to determine the response of the material to the load and climatic factors around the road.

The selection of asphalt, aggregates and utilization waste materials into asphalt as additive to increase the strength and resilience of the HMA mixture is one of the HMA quality factors [7,8]. Waste materials such as plastic and tire can be used to improve the quality of the HMA mixture. In addition, the utilization of waste materials in the construction sector can reduce environmental impacts. The addition of plastic and tire waste reduces the asphalt content in the HMA mixture, making it more cost-effective. Therefore, this research was carried out and developed to obtain high-quality HMA.

Separately adding plastic and tire waste into HMA has yielded positive outcomes. The addition of HDPE plastic waste 2-4% into AC-BC mixture has met Marshall criteria and is weather resistant [9]. Another study found that including 6% LDPE plastic in the Asphalt Concrete Wearing Course (AC-WC) improved stability and durability [10,11,12]. Meanwhile, adding 5.3 percent LDPE plastic to the Asphalt Concrete Binder Course (AC-BC) mixture improved its stability and durability [13]. Utilization of 3% tire waste in asphalt concrete mixture increased its flexibility and durability [14]. Another study showed that the addition of 3% tire waste increased the deformation resistance [15]. The results of other studies concluded that by adding 6% of tire waste produced the highest stability [16].

Some of the studies above only tested the effect of one plastic or tire waste separately on the asphalt-concrete mixture with one type of test. Marshall testing has not been conducted to investigate the performance of asphalt mixtures using a combination of plastic and tire waste on previous research. It is critical to do research on the effect of combining plastic and tire waste in HMA using Marshall criteria in order to assess its performance.

Therefore, the purpose of this study was to construct an analytical theory and use Marshall testing to investigate the effect of adding plastic and tire trash on HMA performance. The findings of this study will be valuable in developing theoretical studies for scholars and making recommendations to Indonesian road building stakeholders.

RESEARCH AND METHODOLOGY

This research was conducted on the laboratory. The scope of testing included physical material, Optimum Asphalt Content (OAC), and Marshall testing. The added material of plastic and tire waste was cut into small pieces (powder) by hand and mixed with asphalt at a concentration of 1-3 percent.. The addition waste materials content was determined through trial and error in compliance with Bina Marga 2018 specifications for modified asphalt. Furthermore, an HMA mixture of Asphalt Concrete Wearing Course (AC-WC) was made.

Material Testing

Material testing included: asphalt and aggregate. For added materials, plastic and tire waste must be dry and clean. The requirements for aggregate and asphalt follow the general specifications for HMA, Bina Marga, 2018. Material testing was the initial requirement in determining the material used as asphalt mixture. Table 1, Table 2, and Table 3 show the summary of the aggregate and asphalt test standards for HMA mixtures.

TABLE 1. Aggregate Specification

No.	Test type		Requirement	Standard
A. Course Aggregate				
1	Abrasion with Los Angeles machine	100 rotation	Max. 8%	SNI 2417:2008
		500 rotation	Max. 40%	
2	Bulk specific gravity (gr/cc)		>2.5	SNI 20-1969-2008
3	SSD specific gravity (gr/cc)		>2.5	SNI 20-1969-2008
4	Apparent specific gravity (gr/cc)		>2.5	SNI 20-1969-2008
5	Water absorption (%)		<3%	SNI 20-1969-2008
6	Aggregate adhesiveness to asphalt (%)		Min. 95%	SNI 7619:2012
B. Fine Aggregate				
1	Bulk specific gravity (gr/cc)		>2.5	SNI 20-1970-2008
2	SSD specific gravity (gr/cc)		>2.5	SNI 20-1970-2008
3	Apparent specific gravity (gr/cc)		>2.5	SNI 20-1970-2008
4	Water absorption (%)		<3%	SNI 20-1970-2008
5	Aggregate passing sieve No. 200 (%)		Max. 10%	SNI ASTM C117:2012
C. Filler				
1	Specific gravity (gr/cc)		2.25 – 2.7	SNI 03 - 2460 - 1991
2	Filler passing sieve No. 200		> 75%	SNI 03 - 6723 - 2002

TABLE 2. Asphalt PEN 60/70 Specification

No.	Test type	Requirement	Standard
1	Penetration at 25°C (0.1 mm)	60-70	SNI 2456:2011
2	Kinematic viscosity 135°C (cSt)	≥ 300	SNI 7729:2011
3	Softening point (°C)	≥ 48	SNI 2434:2011
4	Ductility at 25°C, (cm)	≥ 100	SNI 2432:2011
5	Flash point (°C)	≥ 232	SNI 2433:2011

6	Specific gravity	≥ 1	SNI 2441:2011

TABLE 3. Modification Asphalt Specification

No.	Test type	Requirement	Standar
1	Penetration at 25°C (0.1 mm)	Min.40	SNI 2456:2011
2	Kinematic viscosity 135°C (cSt)	≤ 3000	SNI 7729:2011
3	Softening point (°C)	≥ 54	SNI 2434:2011
4	Ductility at 25°C, (cm)	≥ 100	SNI 2432:2011
5	Flash point (°C)	≥ 230	SNI 2433:2011
6	Specific gravity	≥ 1	SNI 2441:2011

Determination of Optimum Asphalt Content (OAC)

It is very important to determine the proportion of asphalt and aggregate in the asphalt mixture in the job mix design. Determination of the OAC (Pb) was carried out in two stages, first the calculation of estimated Pb (Pbe) and Pb from Marshall test results. Pbe is the initial stage of the approach to the optimum asphalt content value from the empirical equation, while Pb is used in the mix design as a result of the Marshall test. Here is the Eq. (1) for Pbe:

$$Pbe=0{,}035(\%CA)+0{,}045(\%FA)+0{,}18(\%FF)+C \qquad (1)$$

Where;
Pb= optimum asphalt content (OAC)
CA= course aggregate (%)
FA= fine aggregate (%)
FF= filler (%)
C= constant: 0.5-1 (Asphalt Concrete: AC)
From the Pbe results, 15 specimens were made for Marshall testing in determining the Pb value.

Marshall Testing

This study was aimed to determine the performance of HMA with added plastic and tire waste using the Marshall testing. The cleaned plastic and tire waste were cut into small pieces (powder) and mixed into the AC-WC mix with varying levels of 1%, 2%, and 3% of Pb. The AC-WC aggregate gradation designed following the Bina Marga 2018 specification. The AC-WC mixture consisted of 9 test specimens. Stability, flow, and Marshall Quotient (MQ) were obtained during Marshall testing (MQ). Meanwhile, specific gravity, Void in Mix (VIM), Void in Mineral Aggregate (VMA) and Void Filled with Asphalt (VFA) were included in the volumetric of Marshall specimen.

RESULTS AND DISCUSSION

Characteristics of Material

Table 4 shows that the selected aggregate has met all the material criteria for the HMA mixture. The aggregate used has a high level of strength and adhesion with a low level of water absorption.

TABLE 4. Aggregate properties

No.	Test type		Value
A.	**Coarse aggregate**		
1	Abrasion with Los Angeles machine (%)	100 rotation	3
		500 rotation	17
2	Bulk specific gravity (gr/cc)		2.80
3	SSD specific gravity (gr/cc)		2.84
4	Apparent specific gravity (gr/cc)		2.92
5	Water absorption (%)		1.49
6	Aggregate adhesiveness to asphalt (%)		100
B.	**Fine aggregate**		
1	Bulk specific gravity (gr/cc)		2.61
2	SSD specific gravity (gr/cc)		2.64
3	Apparent specific gravity (gr/cc)		2.69
4	Water absorption (%)		1.13
5	Aggregat passing sieve No. 200 (%)		8.91
C.	**Filler: stone ash**		
1	Specific gravity (gr/cc)		2.395
2	Filler passing sieve No. 200 (%)		81.30

Similarly, Table 5 shows that the selection of 60/70 penetration asphalt has met the specifications of Bina Marga specification 2018. The results of the test show that all asphalt penetration values are within the range of the 60/70 asphalt penetration criteria.

TABLE 5. Asphalt PEN 60/70 properties

No.	Test type	Value
1	Penetration at 25°C (0.1 mm)	68.7
2	Kinematic viscosity 135°C (cSt)	1302.7
3	Softening point (°C)	56.5
4	Ductility at 25°C, (cm)	117.4
5	Flash point (°C)	240.6
6	Specific gravity	1.14

Table 6 shows that the addition of waste materials content in the 60/70 penetration bitumen reduced the penetration and ductility values. While the value of viscosity, softening point and flash point increasing. From these parameters, the addition of waste materials has an impact on increasing the penetration strength of asphalt 60/70.

TABLE 6. Modification Asphalt properties

No.	Test type	% level of plastic and tire waste		
		1%	**2%**	**3%**
1	Penetration at 25°C (0.1 mm)	56.7	54.9	44.9
2	Kinematic viscosity 135°C (cSt)	1505.9	1719.1	1935.97
3	Softening point (°C)	63.0	66.0	70.3
4	Ductility at 25°C, (cm)	109.3	103.8	100.5
5	Flash point (°C)	250.6	257.8	259.3

Optimum Asphalt Content (OAC)

At the initial stage by using equation (1), the value of Pbe = 5.5% is obtained. This Pbe value is used as the basis for finding Pb for making the Marshall test mix design. The following are the results of the Marshall test to determine the Pb value. Table 7 shows that the Pb value = 5.5%. Furthermore, this Pb = 5.5% will be used in the Marshall mix design test of a HMA mixture with added materials of plastic and tire waste.

TABLE 7. Optimum Asphalt Content (OAC) value

Criteria	ACWC specification	% Asphalt content				
		4.5	**5**	**5.5**	**6**	**6.5**
Density	-					
VFA (%)	>65					
VIM (%)	3-5					
VMA (%)	> 15					
Stability (Kg)	> 1000					
Flow (mm)	2-4					
MQ (Kg/mm)	>250					
		OAC = 5.5%				

Characteristics of Marshall

The performance of the HMA mixture can be seen from the Marshall test results. Marshall test results show two conditions of the sample in dry and wet. The following are the results of the Marshall HMA characteristic test with added plastic and tire waste.

Stability

Figure 1 shows that the stability of the HMA mixture with added plastic and tire waste is higher than the HMA mixture without waste materials. The highest stability was at 1% waste content, which was 2805.03 Kg. Stability dropped at 2% and 3% waste levels. The comparison of dry and wet HMA specimens, the influence of water caused a decrease in the stability value. However, the stability of both dry and wet HMA specimen met the minimum stability criteria of 1000 Kg.

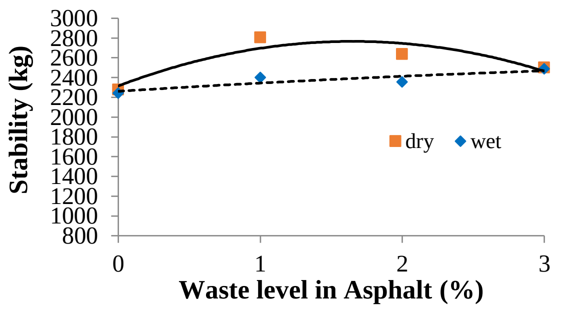

FIGURE 1. Correlation between Stability and Waste Level

Flow

Figure 2 shows that the flow of the HMA mixture with plastic and tire waste is lower than the HMA mixture without waste materials. Flow will decrease along with the addition of waste levels. The lowest flow at 3% waste content, which is equal to 3.43 mm. At 1% effluent content, a flow of 4.1 mm was obtained which did not meet the maximum standard 4 mm. The water immersion factor affects the flow increase, so the sample is more susceptible to deformation. Samples of immersion conditions for all levels of waste materials met the flow criteria 2-4 mm.

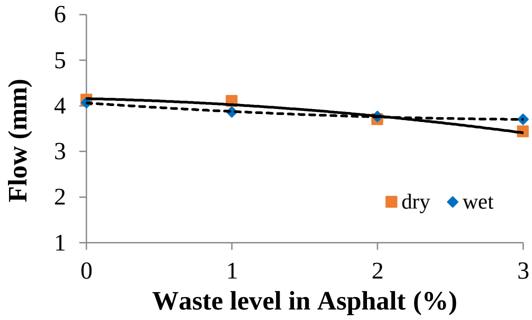

FIGURE 2. Correlation between Flow and Waste Level

Marshall Quotient (MQ)

Figure 3 shows that the MQ of the HMA mixture with plastic and tire waste is higher than the HMA mixture without waste materials. MQ will increase along with the increase in the level of waste materials in the HMA mixture with the highest MQ value at 3% waste content of 730.59 Kg/mm. Besides that, the effect of water immersion will be able to reduce MQ. The MQ of the dry and wet specimens met the minimum standard of 250 Kg/mm.

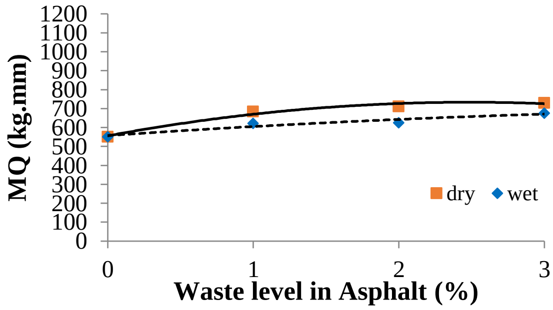

FIGURE 3. Correlation between MQ and Waste Level

Void in Mixture

Figure 4 shows that the VIM of a mixture of HMA with plastic and tire waste is higher than that of a HMA mixture without waste materials. The lowest VIM was obtained at 1% waste content at 4.31% and the highest at 2% waste content at 4.8%. VIM decreased at 3% waste content to 4.58%. Specimens with submerged condition had a lower VIM than specimens in dry condition. Water filled the specimen pores, thereby lowering the VIM of the HMA mixture. Both dry and wet specimens had VIM which was still within the range of standard criteria 3.5-5%.

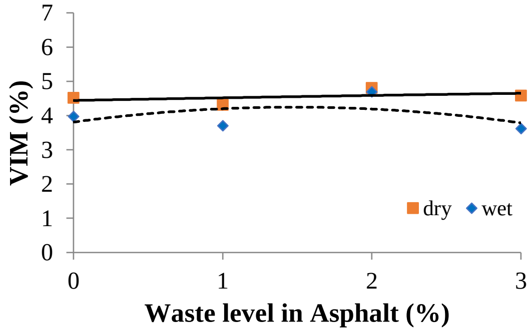

FIGURE 4. Correlation between VIM and Waste Level

Void Filled with Asphalt

Figure 5 shows that the VFA of a HMA mixture with waste materials is higher than HMA mixture without waste materials. The highest VFA at 1% waste content is 80.96% and decreased at 2-3%. The VFA of the submerged specimens was lower than dry specimens. The VFA of both dry and wet specimens met the minimum standard of 65%.

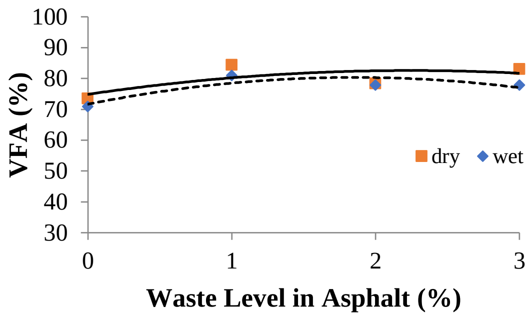

FIGURE 5. Correlation between VFA and Waste Level

Void in Mineral Aggregate

The VMA of the HMA mixture with plastic and tire waste is higher than the VMA of the HMA mixture without waste materials, as shown in Figure 6. VMA is 15.56 percent when there is 1% waste content, 15.90 percent when there is 2% waste content, and 15.80 percent when there is 3 percent waste content. In the submerged specimens, the VMA was lower than in the dry specimens. Both dry and wet samples were found to meet the minimum standard requirements of 15%.

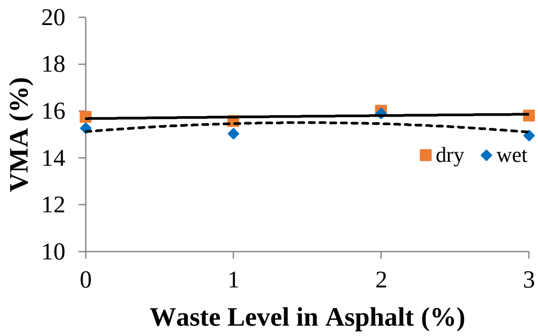

FIGURE 6. Correlation between VMA and Waste Level

Proposed HMA Mix Design Containing Waste Materials

The inclusion of plastic and tire waste to the HMA mixture is an attempt to improve the HMA mixture's ability to deal with the effects of climate change while also reducing environmental problems caused by waste accumulation. As a result, the properties of the HMA mixture with added waste materials can be assessed after the laboratory performance testing stage by Marshall testing to identify which mix design produces the best performance.

The proposed mix design for the HMA mixture formed from additional plastic and tire trash is shown in Figure 7. HMA-OAC design, determining the percentage of waste materials content, then manufacturing modified HMA, Marshall testing, determining the optimal waste materials content (OWC), and mix design of HMA mix that generates optimum performance are all stages of the mix design process.

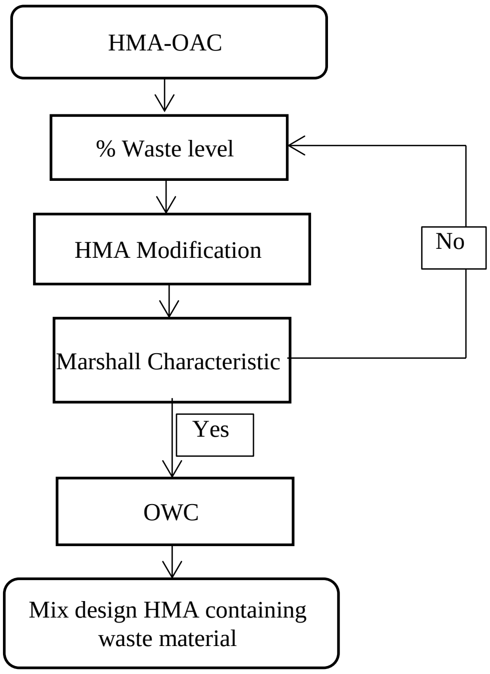

FIGURE 7. HMA Mix Design containing Waste Materials

Furthermore, Table 8 shows the process of determining OWC. The calculation results shows OWC of 2.5%.

TABLE 8. Determination of OWC

No.	Criteria	ACWC specification	% Waste Level			
			0	**1**	**2**	**3**
1	Density	-				
2	VFA(%)	>65				
3	VIM (%)	3 s/d 5				
4	VMA (%)	> 15				
5	Stability (Kg)	> 1000				
6	Flow (mm)	2 s/d 4				
7	MQ (Kg/mm)	>250				
Optimum of Plastic and Tire Waste (OWC)			2.5%			

CONCLUSION

From the results of this study, it can be concluded that the utilization of plastic and tire waste improved the performance of the HMA mixture. This can be seen by increasing the parameters of the Marshall mixture characteristics. However, the effect of water soaking the HMA mixture can reduce the performance of the HMA mixture. The addition of 2-3% waste materials content in the HMA mixture resulted in the performance of the HMA mixture that met the Marshall criteria. This study also proposes a mix design for the utilization of plastic and tire waste with an optimum waste content of 2.5%.

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