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Use of crumb rubber as an additive in asphalt concrete mixture

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Abstract

As the rapidly growing number of vehicles in Indonesia, the waste of tire rubber becomes a major environmental concern. The use of crumb rubber, which is the recycled tire rubber, as an additive in hot mix asphalt mixture is considered as a sustainable construction method. The purpose of this study was to investigate the effect of adding crumb rubber to asphalt mixture using wet process. The laboratory hot mix asphalt design tests were done by Marshall Method procedure. In this study, two different crumb rubber contents (1% and 2% by weight of asphalt mixture) and two different crumb rubber sizes (#40 and #80) were investigated. A comparative study was done among the unmodified and modified asphalt concrete mixtures considering the Marshall Stability value and the volumetric properties. The results showed that crumb rubber is recommended as an additive in asphalt mixture, as all the test results are within the standard requirements. The addition of crumb rubber tended to increase the strength and quality of asphalt mixture. However, it should be more concern about durability of asphalt mixture because of the lower asphalt content in crumb rubber modified asphalt mixture.

Keywords: asphalt concrete; crumb rubber; Marshall Stability; hot mix asphalt; wet process

1. Introduction

As the rapidly growing number of vehicles in Indonesia, the waste of tire rubber becomes a major environmental concern. The use of crumb rubber, which is the recycled tire rubber, as an additive in asphalt mixture is considered as a sustainable construction method. There have been many investigations on crumb rubber modified asphalt mixtures [1,2,3,4,5,6]. The addition of crumb rubber to the bitumen binder enhanced the physical properties of rubberised bitumen binder as indicated by reduction in penetration and ductility [1]. Laboratory test results show that crumb rubber modified asphalt mixture could improve the characteristics of asphalt mixtures [2, 3, 4].

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There are two basic process for adding crumb rubber in asphalt mixture, wet and dry process [5]. In wet process, crumb rubber is added to hot asphalt and allows the rubber and asphalt to react. The main process of wet process is swelling of the rubber. In dry process, crumb rubber is mixed with the hot aggregate prior to adding the bitumen. The addition of tire rubber in asphalt mixtures using dry process could improve the properties of resistance to permanent deformation at high temperature and cracking at low temperature [6]. The rubberized asphalt mixture with wet process could obtain the desired volumetric parameters as specified [3]. The purpose of this study was to investigate the effect of adding crumb rubber to asphalt mixture using wet process.

2. Research methodology

2.1 Materials

In this study, asphalt Pertamina with 60/70 penetration grade was selected. This study applied crumb rubber as additive in asphalt mixture. The sizes of crumb rubber used were no. 40 (0.42 mm) and no. 80 (0.177 mm). The coarse and fine aggregates used for this research was supplied from Pandaan (East Java Province, Indonesia).

2.2 Preparations of asphalt mixtures

Marshall Mix Design Method was applied throughout this study, for the unmodified and crumb rubber modified asphalt concrete mixture. This mix design method is commonly used to design the asphalt mixtures in Indonesia. In this study, several stages of laboratory examination were conducted. First stage was aggregate selection, including the determination of aggregate physical properties and the composite gradation for asphalt mixtures to meet the specification requirements. This specification was referring to General Specification 2010 (Revised 3) of the Department of Public Works of Indonesia [7]. Second stage was asphalt evaluation for both asphalt mixtures, unmodified asphalt concrete and crumb rubber modified asphalt mixtures, and also estimating of the asphalt optimum content for each asphalt mixtures. At the end, verification of the volumetric parameters was done. Three samples for each mixture were prepared.

Adding crumb rubber to asphalt mixtures was conducted based on wet process. The amounts of the crumb rubber were 1% and 2% by weight of asphalt mixture. Asphalt was heated at high temperature (about 150°C) before mixing with crumb rubber. The mixing temperature was kept constant in between 135-150°C. The mixing process was done manually until a homogenous mixture was reached. The crumb rubber asphalt mixture was then added to the hot aggregate. This study was done for two different crumb rubber sizes.

3. Results and discussion

3.1 Aggregates

Laboratory test results for general properties aggregate is shown in Table 1. Sieve analysis results of tested aggregates are shown in Figure 1 and Table 2. Table 2 also shows combined aggregate gradation for asphalt mixture. It was determined according to the specification requirement.

Table 1. Properties of coarse, medium and fine aggregates

Aggregate properties	Standard Test Method	Standard Requirements	Test Results
	Coarse and medium aggregates		
Bulk specific gravity	SNI 1969:2008	Min 2,5	2.772
Apparent specific gravity	SNI 1969:2008	-	2.854
Effective specific gravity	SNI 1969:2008	-	2.772
Water absorption	SNI 1969:2008	Max 3 %	1.695%
Los Angeles Abrasion	SNI 2417:2008	Max 40%	28.76%
Flakiness and elongation index	ASTM D - 4791	Max 10 %	9.29%
Adhesion of mineral aggregate to hot bitumen	SNI 2439:2011	Min 95	>95
	Fine Aggregates		
Bulk specific gravity	SNI 1969:2008	Min 2,5	2.754
Apparent specific gravity	SNI 1969:2008	-	2.844
Water absorption	SNI 1969:2008	Max 3 %	1.142

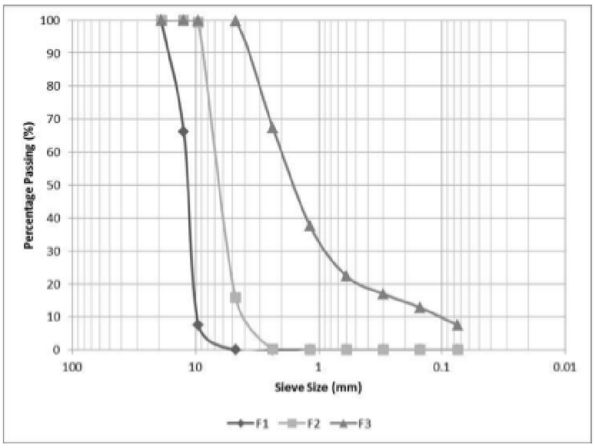

Fig 1. Sieve analysis results of tested aggregates

Table 2. Combined aggregate gradation for asphalt mixture

Sieve Size (mm)	Coarse Aggregate (F1) 10-15 mm		Medium Aggregate (F2) 5-10 mm		Fine Aggregate (F3) 0-5 mm		Filler Cement	Combined Aggregate	Specification
	% passing	20%	% passing	28%	% passing	50%	2%		
19.1	100.00	20.00	100.00	28.00	100.00	50.00	2	100.00	100
12.7	66.13	13.23	100.00	28.00	100.00	50.00	2	93.23	90-100
9.5	7.64	1.53	99.37	27.82	100.00	50.00	2	81.35	72-90
4.75	0.00	0.00	15.88	4.45	99.71	49.85	2	56.30	43-63
2.36	0.00	0.00	0.18	0.05	67.33	33.66	2	35.71	28-39.1
1.18	0.00	0.00	0.00	0.00	37.64	18.82	2	20.82	19-25.6
0.6	0.00	0.00	0.00	0.00	22.49	11.24	2	13.24	13-19.1
0.3	0.00	0.00	0.00	0.00	17.03	8.51	2	10.51	9-15.5
0.150	0.00	0.00	0.00	0.00	12.84	6.42	2	8.42	6-13
0.075	0.00	0.00	0.00	0.00	7.57	3.78	2	5.78	4-10

3.2 Physical properties of asphalts

Properties of asphalt and modified asphalt are shown in Table 3 and Table 4. It was observed that higher crumb rubber content had strongly effect on reducing penetration and ductility of asphalt, otherwise, the softening point had increased. All physical properties of asphalt were within standard requirements.

Lower penetration and higher softening point in crumb rubber modified asphalt indicated that crumb rubber made the asphalt more stiff, but also reduced the flexibility of modified asphalt. Lower ductility showed that asphalt had poor adhesive properties. A decrease in ductility value can be explained that modified asphalt was made by manual blending process and it has effects on the physical interactions of the bitumen and crumb rubber. [1] The blending process was a critical step to ensure a homogenous mixture. Homogeneity is crucial to defining asphalt mixture characteristics.

Table 3. Properties of asphalt with 60/70 penetration grade.

Asphalt Properties	Standard Test Method	Standard Requirements (Asphalt 60-70)	Test Results
Penetration at 25°C, dmm	SNI 06-2456-1991	60-70	64.3
Ductility at 25°C, cm	SNI 06-2432-1991	≥ 100	105
Softening Point, °C	SNI 06-2434-1991	≥ 48	52.2
Specific gravity	SNI 06-2441-1991	>1.0	1.03
Flash Point, °C	SNI 06-2433-1991	≥ 232	340

Table 4. Properties of crumb rubber modified asphalt

Asphalt Properties	Standard Test Method	Standard Requirements (Modified Asphalt)	Test Results (Crumb rubber size #40)		Test Results (Crumb rubber size #40)	
			1%	2%	1%	2%
Penetration at 25°C, dmm	SNI 06-2456-1991	Min. 40	41.33	44.00	43.80	41.50
Ductility at 25°C, cm	SNI 06-2432-1991	≥ 100	111	25	98	54
Softening Point, °C	SNI 06-2434-1991	≥ 54	54.06	57.96	57.35	65.35
Specific gravity	SNI 06-2441-1991	>1.0	1.033	1.033	1.033	1.033
Flash Point, °C	SNI 06-2433-1991	≥ 232	334	345	345	350

3.3 Optimum asphalt content

In order to determine the optimum asphalt content, asphalt content was varied at 5%, 5.5%, 6.0% and 6.5% by weight of asphalt mixture. Three samples were tested for each variation of asphalt content. Optimum asphalt content was determined based on the combined results of Marshall Test, corresponding to the requirement specification. Table 5 shows the optimum asphalt content for all asphalt mixtures. The crumb rubber does not have a significant effect on optimum asphalt content, but tended to decrease optimum asphalt content of asphalt mixture.

Table 5. Optimum Asphalt Content

Type of asphalt mixture	Unmodified asphalt mixtures	Crumb rubber modified asphalt mixtures (#40)		Crumb rubber modified asphalt mixtures (#80)	
		1%	2%	1%	2%
Optimum asphalt content (%)	6.0	5.5	5.3	5.5	5.5

3.4 Marshall Test Results

Marshall Test results for all asphalt concrete mixture are shown in Table 6. These Marshall and flow tests were conducted based on the determined optimum asphalt content for each asphalt concrete mixture. The use of crumb rubber as an additive material in asphalt mixture has satisfactory results, as all the parameters value are within the standard requirements.

Table 6. Comparison of Marshall Test results for all asphalt concrete mixtures

Type of asphalt mixture	Unmodified asphalt	Crumb rubber modified asphalt mixtures (#40)		Crumb rubber modified asphalt mixtures (#80)		Standard requirements (SNI 8198:2015)
		1%	2%	1%	2%	
Marshall Stability (kg)	1033.35	1210.10	1228.38	1393.53	1418.50	Min 800 (for unmodified asphalt concrete mixtures) Min 1000 (for modified asphalt concrete mixtures)
Flow (mm)	3.56	3.56	3.22	3.56	3.30	3-4.5
Marshall Quotient (kg/mm)	290.62	340.58	382.39	398.71	430.32	Min 250 (for unmodified asphalt concrete mixtures) Min 300 (for modified asphalt concrete mixtures)
VFB (%)	79.11	77.45	74.66	76.03	75.69	Min 65
VIM (%)	3.71	3.76	4.25	3.74	3.81	3-5 (for unmodified asphalt concrete mixtures) 3-5.5 (for modified asphalt concrete mixtures)
VMA (%)	17.78	16.63	16.74	15.60	15.66	Min 15

From the results of Marshall Test, it was observed that the higher crumb rubber content and finer crumb rubber cause an increase in Marshall Stability and Marshall Quotient. On the contrary, the addition of crumb rubber decreases flow parameter.

Marshall Quotient, which is ratio of stability to flow, indicates the strength and quality of asphalt mixture. The higher Marshall Quotient value shows the asphalt mixture has more stiffness and strength to cracking. Hence, the asphalt mixture has more resistance in permanent deformation. It is also shown, for higher crumb rubber content, flow tends to decrease. Lower flow value indicates the mixture has insufficient asphalt content and become more stiff. It is as shown on a decrease in optimum asphalt content (Table 5).

It was also shown the addition of crumb rubber decreases Voids Filled with Bitumen (VFB). VFB is the voids in the mineral aggregate filled with asphalt. The decrease in VFB indicates a decreasing effective asphalt film thickness, which results lower durability of asphalt mixtures.

Void in Mixture (VIM) tends to increase in higher crumb rubber content but decrease in finer crumb rubber. VIM shows the air void content. The higher air voids content decreases asphalt content in mixture. This result is as shown on a decrease in optimum asphalt content (Table 5).

The addition of crumb rubber decreases Void in Mineral Aggregate (VMA). It was also observed that the finer crumb rubber caused a decrease in VMA. The lower VMA indicates the less space is available for the asphalt film, however, a durable asphalt mixture requires an adequate asphalt film thickness.

4. Conclusions

Based on the results of laboratory investigation, conclusions of this research are described as the following,

1. Crumb rubber is recommended as an additive in asphalt mixture, as all the test results are within the standard requirements.
2. The addition of crumb rubber tends to increase the strength and quality of asphalt mixture. It is shown by an increase in stability and a decrease in flow.
3. Crumb rubber modified asphalt mixture needed less asphalt content. However, low asphalt content increases air void in mixture and thus mixture permeability increases. As permeability increases, asphalt mixture becomes less durable. Therefore, it should be more concern about durability of asphalt mixture because of the lower asphalt content in crumb rubber modified asphalt mixture.

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