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Marshall Test Characteristics of Asphalt Concrete Mixture with Scrapped Tire Rubber as a Fine Aggregate

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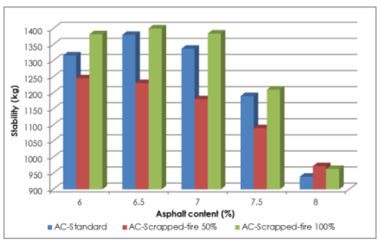
Graphical abstract



Abstract

Highways are important transportation infrastructures that influence economy, culture, and security. Most of the highways in Indonesia are flexible pavement that use asphalt as a binder. The use of scrapped tire rubber as a partial replacement of fine aggregates is based on the limited available natural aggregate in nature. Utilization of scrapped tire rubber as a fine aggregate is one of the alternatives for reducing environmental pollution and supporting Clean Development Mechanism program. The aim of this study is to analyze the Marshall test characteristics of asphalt concrete (AC) mixture that use scrapped tire rubber as a partial substitute of fine aggregate and comparing with a standard mixture. Laboratory tests are performed on three different types of mixtures as follows the mix without scrapped tire rubber, mix containing 50%, and 100% substitution of aggregate at fraction of No.50 with scrapped tire rubber. The test, it show that optimum asphalt content for $AC_{Standard}$ mixture is 6.76%, while $AC_{Scrapped\text{-}tire\ 50\%}$ mixture is 7.04% and $AC_{Scrapped\text{-}tire\ 100\%}$ mixture is 6.25%. The use of scrapped tire rubber in asphalt concrete mixtures can improve the resistance to permanent deformation and resistance to water. The use of scrapped tire rubber is acceptable as a partial replacement of aggregate in asphalt concrete mixtures.

Keywords: Asphalt concrete mixture, scrapped tire rubber, Marshall test, aggregate substitute

1.0 INTRODUCTION

In Indonesia, highways serve nearly 80-90% population mobility and flow of goods, so that the development of road transport infrastructure is a priority. It is reflected by the amount of national budget absorbed for the construction of new road or maintenance of roads [1, 2]. In the 2014 Indonesian National Budget (*Anggaran Pendapatan Belanja Negara* (APBN)), the Ministry of Public Works Republic of Indonesia allocated funds amounting to IDR 84.1 trillion [3]. The impact of this activity is increasing need for both asphalt and natural aggregate (coarse and fine aggregate). The asphalt is imported as many as 600,000 tons per annum [4]. It results in reducing availability of foreign exchange and also diminishing aggregates [2, 4].

End-of-life tires have become a voluminous problem in many countries. In Europe 2,000,000 tons of end-of-life tires are generated each year and these need to be recycled or disposed [5]. The recovered end-of-life tires, including historical stockpiles in Japan 1,000,000 tons and 3,750,000 in United States that need to be taken care of in order to reduce the risk of fire and environmental concern from leachate in stockpiles [6]. More than 273 million scrap tires are produced in United States each year. In addition to this, more than 300 million tires are currently stockpiled throughout The United States [7]. These stockpiles are dangerous not only from potential environmental threat, but also from fire hazards and provide breeding grounds for mosquitoes [8].

Over the years, disposal of tires has become one of the serious problems in environments, and landfilling is becoming unacceptable because of the rapid depletion of available sites for waste disposal. Used tire are required to be shredded before landfilling. Innovative solutions to meet the challenge of tire disposal problem have long been in development, and the promising options are; (i) use of tire rubber in asphalt mixtures, (ii) thermal incineration of worn-out tires for the production of electricity or steam, and (iii) reuse of ground tire rubber in number of plastic and rubber products [9]. The utilization of scrapped tire rubber waste is one of the alternatives for reducing environmental pollution and supporting Clean Development Mechanism (CDM) program. CDM is regarded as one of the most important internationally implemented market-based mechanisms to reduce carbon emissions [10].

Asphalt concrete is a construction layer consisting of mixture of asphalt and continuously graded aggregate, mixed, spread, and compacted at a specific temperature. Layers of asphalt concrete consists of mixture of three types namely Asphalt Concrete-Wearing Course (AC-WC), Asphalt Concrete-Binder Course (AC-BC), and Asphalt Concrete Base (AC-Base) with maximum aggregate size of 19, 25.4, and 37.5 mm respectively [11].

The use of scrapped tire rubber as an aggregate substitute in asphalt concrete mixtures has been investigated by the United State Department of Transportation-Federal Highway Administration in the United States since 1986. As a result the use of scrapped tires rubber tires can reduce damage in the flexible pavement that caused by weather factors and traffic [12]. The use of scrapped tires grater is suitable for use in hot climates [13]. Road Research Centre, Ministry of Public Works in Kuwait stating the addition of 2% and 5% latex grated old tires on asphalt can prevent cracked, bleeding, and minimize the release of grains on the surface of flexible pavements [13].

The use of tire shreds in construction work has been tested since the 1980's, mainly as a road insulation material, lightweight fill material and as drainage layers in landfills, e.g. MPCA (1990), Manion and Humphrey (1992) in [14]. Based on ASTM D-6270-08, the use of scrap tires including: tire derived aggregate (TDA) comprised of pieces of scrap tires, TDA/soil mixtures, tire sidewalls, and whole scrap tires in civil engineering applications [15]. This includes use of TDA and TDA/soil mixtures as lightweight embankment fill lightweight retaining wall backfill, drainage layers for roads, landfills and other applications, thermal insulation to limit frost penetration beneath roads, vibration damping layers for rail lines, and replacement for soil or rock in other fill applications. Use of whole scrap tires and tire sidewalls includes construction of retaining walls, drainage culverts, road-base reinforcement, and erosion protection, as well as use as fill when whole tires have been compressed into bales [15]. The use of scrapped rubber tires in asphalt concrete mixtures can improve the resistance to permanent deformation due to ruts [16]. The addition of powder materials such as scrapped tires rubber in asphalt mixture can provide better resistance to high temperatures and loads, as compared with asphalt without the addition material. The addition of additive in asphalt concrete mixture can improve the shear resistance at high temperature so as to prevent the damage of road [17].

The use of rubber as bitumen additive gave results that the addition of both latex and Scrapped Tire Rubber (STR) into bitumen could decrease in penetration value and specific gravity of bitumen and increase in softening point value of bitumen [18], but it was different result obtained for ductility value of bitumen. The addition of latex did not influence the ductility value, but the addition of STR could reduce the ductility value [19]. Polymer rubber in tires has been used as an additive to improve the bonding strength of asphalt with aggregate. This means that as well as environmental problems, used tires are not burned useless. In connection with environmental issues, some countries are already running recycled asphalt, asphalt roads damaged not patched with new asphalt but use recycled asphalt [20]. The addition of scrapped tire rubber to ±3% in asphalt concrete mixture produces better performance, especially for conditions of temperature above 30°C. Aggregate substitute in fraction No. 50 with scrapped tires rubber can add hot rolled asphalt mixture resistance to water so as to reduce damage of the road [1]. Tire shreds resist clogging even at high intrusion of fine soil material. The resistance against leachate degradation has been tested on different leachates, e.g. acidic, and has proven to be persistent [21].

The use of waste tire rubber (rubber granule) as aggregate in the production of concrete paving block with double layers gave results the percentage of waste tire rubber content for double layer rubberized concrete paving blocks (DL-RCPB) affects the density, porosity, and compressive strength. The control concrete paving block (CCPB) and DL-RCPB (10%) achieve the minimum strength requirement of 45 MPa. The density of DL-RCPB (40%) recorded reduce 24% as compared to CCPB. At 28 days, the percentage of porosity increased up to 55% when 40% of aggregate were replaced with rubber granule. The skid resistance of concrete block increased by 7% with the incorporation of rubber granule particle size of 1-4 mm and 5-8 mm up to 40% as the replacement of fine aggregate and coarse aggregate [22].

The aim of this study is to analyze the Marshall test characteristics of asphalt concrete mixture that use scrapped rubber tire as a partial substitute of fine aggregate and comparing with a standard mixture. The characteristics of asphalt concrete mixture include the optimum bitumen content based on Marshall test characteristics, value of maximum stability, retained strength index, and index immersion.

2.0 METHODOLOGY

2.1 Materials

Materials that used in this study consist of coarse aggregate, fine aggregate, Portland cement (as filler), scrapped tire rubber, and bitumen penetration 60/70. The materials used in this study, are shown in Figures 1 through 4.

Figure 1 Coarse aggregate [2]

Figure 2 Fine aggregate [2]

Figure 3 Scrapped tire rubber

Figure 4 Bitumen Pen 60/70

2.2 Methods

The method used in this study is an experimental testing in the laboratory. The conducted tests are specific gravity, absorption of water, abrasion with Los Angeles Machine, adhesive of aggregate and asphalt, index of thinness on coarse aggregate. Specific gravity test for fine aggregate, filler and scrapped tire rubber, asphalt test, and Marshall Test. The standards used, are namely the Standard National of Indonesia (SNI) SNI 1969:2008 for specific gravity test [23], SNI 2417:2008 for abrasion test with Los Angeles Machine [24], SNI 03-2439-1991 for adhesive of aggregate and asphalt test [25], and SNI 06-2456-1991 for penetration test of asphalt [26]. Asphalt concrete mixture is designed with absolute density approach in accordance to the design guidelines of Directorate General of Highways, Ministry of Public Works Republic of Indonesia [27]. The aggregate gradation limit specification followed *Bina Marga SKBI* 2.4-26.1987 [28]. The total numbers of samples are 57, 45 for Stage 1 and 12 for Stage 2. Details of tests and number of samples are shown in Table 1.

Table 1 Number of samples in Stage 1 and Stage 2

Sta-ge	Test	Mixture type	Asphalt content (%)	The number of samples	
				Number	Total
1	Marshall Test	$AC_{Standard}$	6.0	3	15
			6.5	3	
			7.0	3	
			7.5	3	
			8.0	3	
		$AC_{Scrapped\text{-}tire\ 50\%}$	6.0	3	15
			6.5	3	
			7.0	3	
			7.5	3	
			8.0	3	
		$AC_{Scrapped\text{-}tire\ 100\%}$	6.0	3	15
			6.5	3	
			7.0	3	
			7.5	3	
			8.0	3	
Total number of samples in Stage 1					45
2	Marshall immersion	$AC_{Standard}$	immersion in 30 minutes		2
			immersion in 24 hours		2
		$AC_{Scrapped\text{-}tire\ 50\%}$	immersion in 30 minutes		2
			immersion in 24 hours		2
		$AC_{Scrapped\text{-}tire\ 100\%}$	immersion in 30 minutes		2
			immersion in 24 hours		2
Total number of samples in Stage 2					12
Total number of samples in Stage 1 and Stage 2					57

3.0 RESULTS AND DISCUSSION

3.1 Aggregate Testing Results

Aggregate tests were conducted to determine the aggregate physical properties and characteristics of coarse aggregate, fine aggregate, scrapped tire rubber, and filler. The scrapped tire rubber is obtained from retread tires in Purwokerto, Central Java, Indonesia. The combined aggregate gradation chosen is a mixture of asphalt concrete fulfilling the highways specifications. The physical properties of the coarse aggregate, fine aggregate, filler, and chemical content of scrapped tire rubber can be seen in Tables 2 to 4.

Based on Table 2, the physical properties of coarse aggregate: crushed stone are the bulk specific gravity of coarse aggregate is 2.57 (the minimum requirement for bulk specific gravity is 2.50 [23], the absorption of water is 1.45% (the maximum requirement for absorption of water is 3.0% [23], the abrasion with Los Angeles Machine 22.77% (the maximum requirement for abrasion is 40% [24], the adhesive of aggregate and asphalt 97% (minimum 95% [25]), and the determination of flakiness index of coarse aggregate is 24.69% (maximum 25%).

Based on Table 3, the physical properties of fine aggregate: filler, and scrapped tire rubber: the bulk specific gravity of fine aggregate is 2.55 (minimum 2.50), the absorption of water of fine aggregate 2.61% (maximum 3.0), the specific gravity of filler is 2.96, and the specific gravity of scrapped tire rubber is 0.972.

The chemical content of scrapped tire rubber is shown in Table 4 [29]. The levels of natural rubber is 25%, the levels of butadiene rubber is 15%, the levels of butyl rubber is 5%, the levels of rubber carbon black is 35%, the levels of ZnO is 4%, the levels oil nepheniclaromatic is 4%, the levels of dirt/dust/kaolin/calcium is 12% and the specific gravity of scrapped tire rubber is 0.98.

Table 2 Physical properties of coarse aggregate: crushed stone

No.	Tests	unit	Value	Specification		Standard
				Min.	Max.	
1.	Bulk specific gravity	-	2.57	2.50	-	SNI 1969: 2008
2.	Absorption of water	%	1.45	-	3.0	
3.	Abrasion with Los Angeles Machine	%	22.77	-	40.0	SNI 2417: 2008
4.	Adhesive of aggregate and asphalt	%	97	95	-	SNI 03-2439-1991
5.	Flakiness index of coarse aggregate	%	24.69	-	25.0	SNI-M-25-1991-03

Table 3 Physical properties of fine aggregate, filler, and scrapped tire rubber

No.	Tests	unit	Value	Specification		Standard
				Min.	Max.	
1.	Bulk specific gravity (fine aggregate)	-	2.55	2.50	-	SNI 1969: 2008
2.	Absorption of water (fine aggregate)	%	2.61	-	3.0	
3.	Specific gravity (filler)	-	2.96	-	-	BS 812 Part:1975
4.	Specific gravity (scrapped tire rubber)	-	0.972	-	-	SNI-06-2441-1991

Table 4 Chemical content of scrapped tire rubber [29]

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	0.98

3.2 Asphalt Test Results

Asphalt test was conducted to determine the characteristics of the material were used in the asphalt mixture. Asphalt bitumen was obtained from PERTAMINA, with penetration 60/70. Asphalt tests include penetration, softening point, flash and fire point, ductility, specific gravity, and viscosity. Asphalt test results can be seen in Table 5. The result of penetration test is 65.85 dmm (specification 60-79 dmm), the softening point of asphalt is 48.25°C (specification 48-58°C), the flash point of asphalt is 332°C (minimum 200°C), the fire point of asphalt is 339°C, and the specific gravity of asphalt is 1.035 (minimum 1.00).

Viscosity test is done using Saybolt-Furol with standard test method ASTM E-102-93 [30]. Viscosity test result in 120°C with duration 432.5 seconds is 942.85 centistokes (cSt), viscosity test result in 140°C with duration 150.5 seconds is 328.09 cSt, and viscosity test result in 160°C with duration 53.5 seconds is 116.63 cSt. The data from the viscosity test results is then plotted on semi-logarithmic graph (the relationship between the kinematic viscosities (in cSt) with temperature in °C, is shown in Figure 5). From Figure 5, the mixture temperature in 170 centistokes is 153°C and the compaction temperature in 280 centistokes is 143.5°C. The relationship between kinematic viscosities (in centistokes) with temperature is formulated in exponential function with Equation (1).

$$Y = 496{,}151e^{-0.0522x} \text{ with } r^2 = 0.97 \quad \text{Equation (1)}$$

In which Y is kinematic viscosities (in cSt) and X is temperature in °C. Coefficient determination (r^2) value 0.97, indicate that between kinematic viscosities and temperature has a very high relationship and the viscosity test using Saybolt-Furol is valid.

Table 5 Asphalt test results [1]

No.	Tests	unit	Specification Min.	Specification Max.	Result	Standard
1.	Penetration,25°C,100gr, 5sec.	dmm	60	79	65.85	SNI 06-2456-1991
2.	Softening point of asphalt	°C	48	58	48.25	SNI 06-2434-1991
3.	Flash point of asphalt	°C	200	-	332	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	-	1.035	SNI 06-2441-1991
7.	Viscosity test in 120°C	cSt	Time: 432.5 seconds		942.85	ASTM E 102-93
	Viscosity test in 140°C	cSt	Time: 150.5 seconds		328.09	
	Viscosity test in 160°C	cSt	Time: 53.5 seconds		116.63	

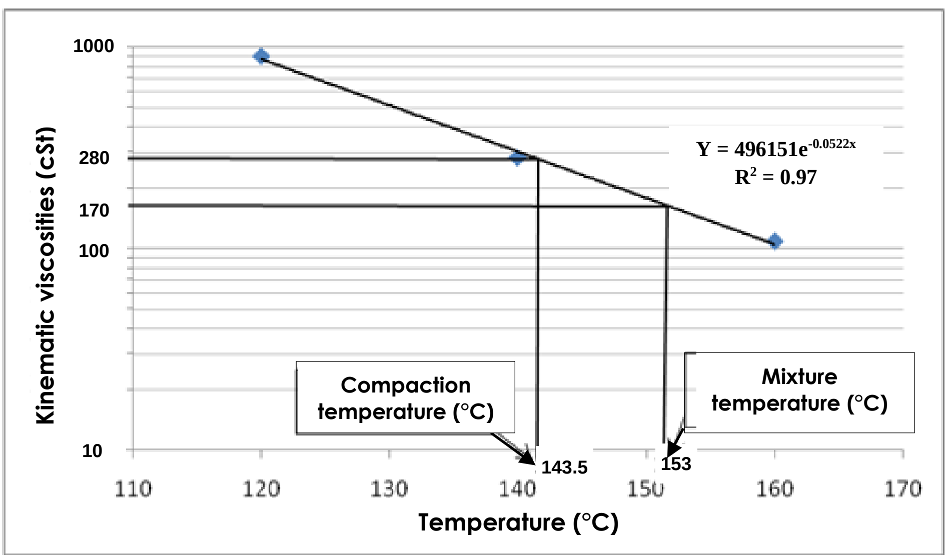


Figure 5 Relationship between the kinematic viscosities (cSt) with temperature (°C)

3.3 Asphalt Cement Test Result

a. $AC_{Standard}$ Test Results

Marshall test results for each mixture of $AC_{Standard}$ with asphalt content range from 6% to 8%. There are six characteristics of Marshall Test: Void in Mineral Aggregate (VMA, % volume), Void in Mixture (VIM, % volume), Voids Filled with Bitumen (VFB, % VMA), stability (kg), flow (mm), and Marshall Quotient (MQ). Marshall Test results for $AC_{Standard}$ mixture can be seen in Table 6.

b. $AC_{Scrapped\text{-}tire\ 50\%}$ and $AC_{Scrapped\text{-}tire\ 100\%}$ Test Results

Six characteristics of Marshall Test results for each mixture of $AC_{Scrapped\text{-}tire\ 50\%}$ and $AC_{Scrapped\text{-}tire\ 100\%}$ with bitumen/asphalt content range from 6% to 8% can be seen in Table 7. The relationship between stability (kg) with asphalt content (%) can be seen in Figure 6. The relationship between flow (mm) with asphalt content (%) can be seen in Figure 7.

c. Results of Testing AC Mixture on Optimum Asphalt Content

The determination of the value of optimum asphalt content for the $AC_{Standard}$ mixture, $AC_{Scrapped\text{-}tire\ 50\%}$ mixture, and $AC_{Scrapped\text{-}tire\ 100\%}$ mixture is shown in Figure 8, Figure 9, and Figure 10, respectively. For the $AC_{Standard}$ mixture, from the six characteristics of Marshall Test: VMA and flow value are appropriate for asphalt content between 6% and 8%. The bitumen content that can satisfy all specification of Marshall Test is from 6.40% to 7.12%. The value of optimum asphalt content of the $AC_{Standard}$ mixture is the median between 6.40% - 7.12% is 6.76% (indicated by the blue arrow in Figure 6). For the $AC_{Scrapped\text{-}tire\ 50\%}$ mixture, asphalt content that satisfies the six characteristics of Marshall Test is between 6.75% - 7.33%. The value of optimum asphalt content of the $AC_{Scrapped\text{-}tire\ 50\%}$ mixture is 7.04% (indicated by the blue arrow in Figure 7). For the $AC_{Scrapped\text{-}tire\ 100\%}$ mixture, asphalt content that satisfies the six characteristics of Marshall Test is between 6.00% - 6.50%. The value of optimum asphalt content of the $AC_{Scrapped\text{-}tire\ 100\%}$ mixture is 6.25% (indicated by the blue arrow in Figure 8).

Table 6 Marshall Test analysis results for $AC_{Standard}$

Characteristic of mixture	Bitumen/asphalt content (%)					Specification
	6.00	6.50	7.00	7.50	8.00	
VMA (%)	18.12	17.25	16.87	17.00	17.38	Min. 14%
VIM (%)	7.54	5.00	3.77	2.67	1.97	3.50-5.50%
VFB (%)	58.38	71.01	77.64	84.29	88.65	Min. 63%
Stability (kg)	1,316	1,380	1,337	1,190	939	Min. 1,000 kg
Flow (mm)	3.25	3.40	3.89	4.50	5.14	Min. 3.00 mm
MQ (kg/mm)	414.33	389.83	352.46	264.44	185.57	Min. 250 kg/mm

Table 7 Marshall Test analysis results for $AC_{Scrapped\text{-}tire\ 50\%}$ and $AC_{Scrapped\text{-}tire\ 100\%}$

Characteristic of mixture	$AC_{Scrapped\text{-}tire\ 50\%}$ Asphalt content (%)					$AC_{Scrapped\text{-}tire\ 100\%}$ Asphalt content (%)					Specification
	6.00	6.50	7.00	7.50	8.00	6.00	6.50	7.00	7.50	8.00	
VMA (%)	17.17	16.90	16.97	17.25	17.77	14.99	14.80	15.11	15.90	17.33	Min. 14%
VIM (%)	6.65	5.00	4.09	3.20	2.67	4.43	3.50	2.20	2.00	1.95	3.50-5.50%
VFB (%)	61.27	70.41	75.90	81.45	85.00	70.45	76.35	85.42	87.42	88.73	Min. 63%
Stability (kg)	1,245	1,230	1,180	1,090	972	1,382	1,400	1,384	1,210	963	Min. 1,000 kg
Flow (mm)	2.63	2.80	3.20	3.75	4.60	2.99	3.67	4.11	4.50	4.74	Min. 3.00 mm
MQ (kg/mm)	475.8	239.3	369.2	290.7	211.5	470.1	381.5	342.3	268.9	205.3	Min. 250 kg/mm

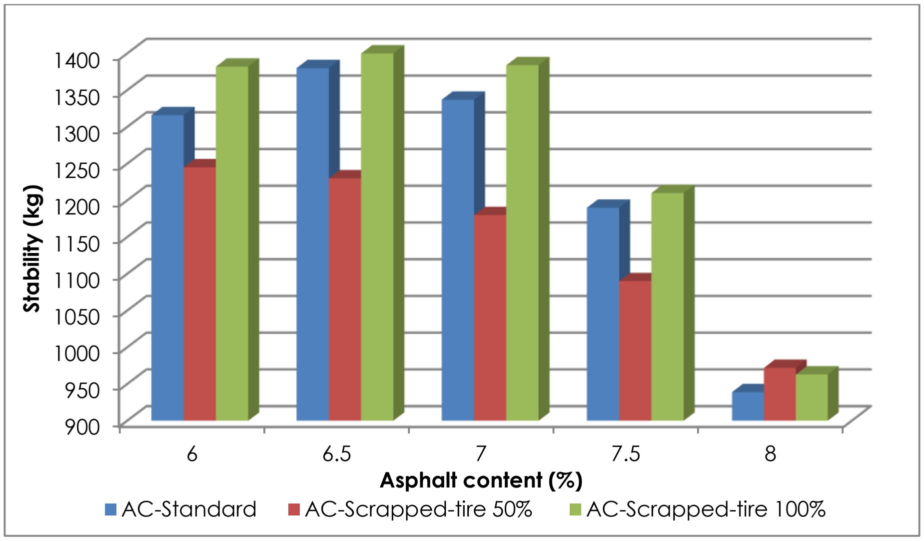


Figure 6 Relationship between the stability (kg) with asphalt content (%)

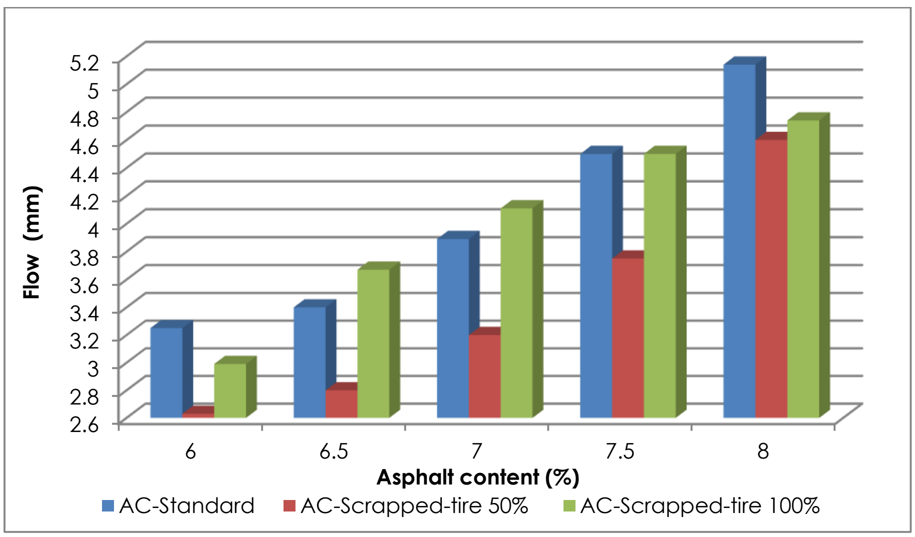


Figure 7 Relationship between the flow (mm) with asphalt content (%)

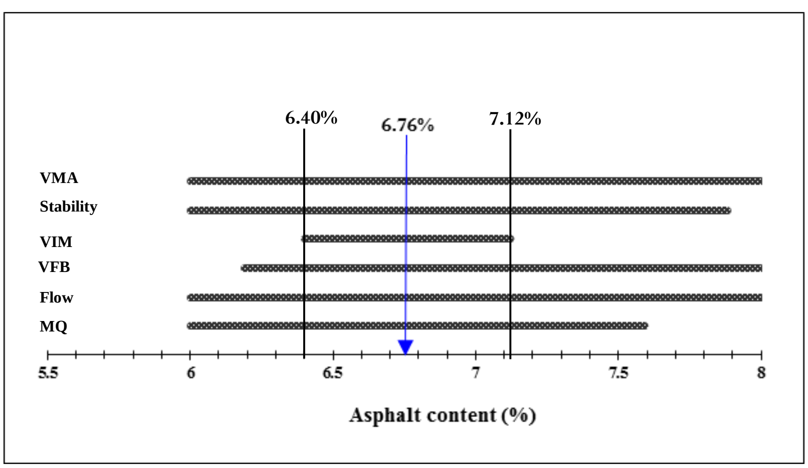


Figure 8 Determination of optimum asphalt content from $AC_{Standard}$ mixture

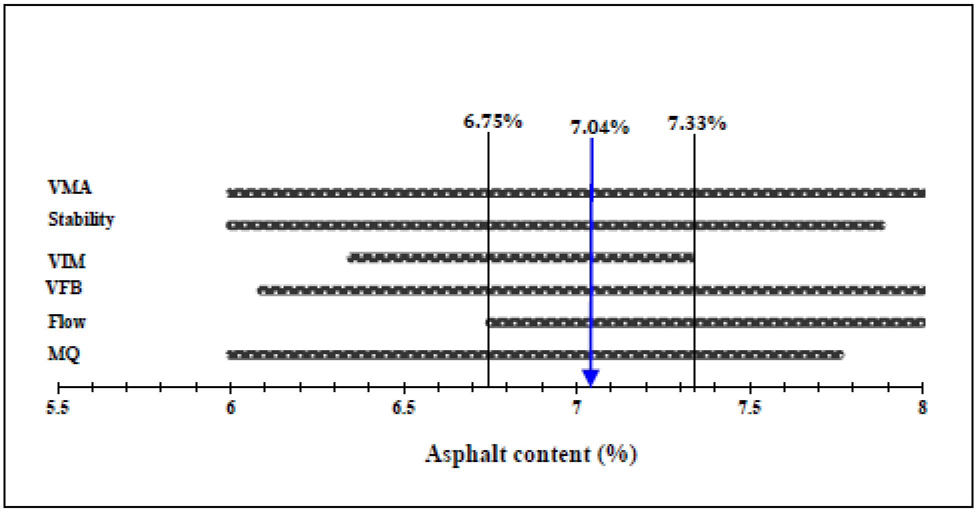


Figure 9 Determination of optimum asphalt content from $AC_{Scrapped\text{-}tire\ 50\%}$ mixture

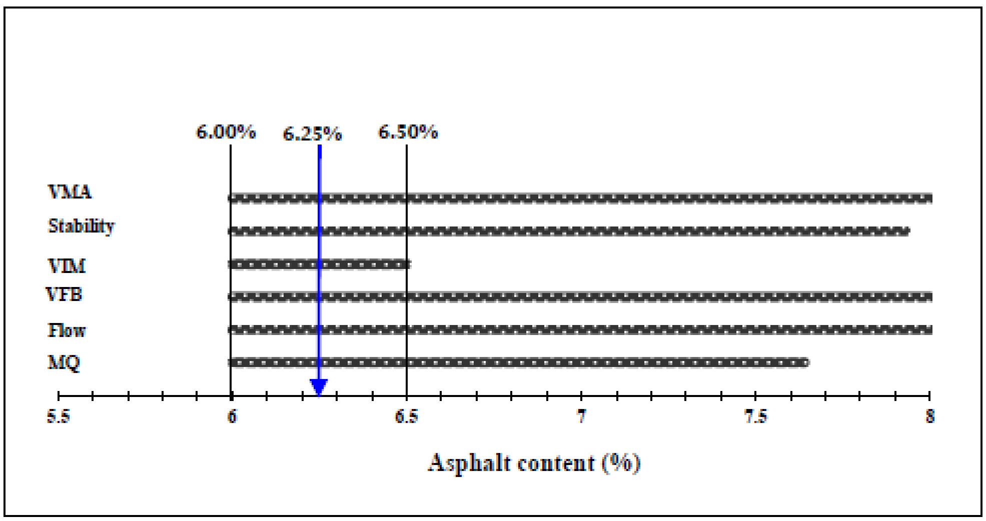


Figure 10 Determination of optimum asphalt content from $AC_{Scrapped\text{-}tire\ 100\%}$ mixture

3.4 Discussion

In Germany, more than 600,000 tons of waste tires were thrown out every year [31]. But, In Indonesia, there still not yet calculated for the waste tires which are thrown out every year. One of the methods to estimate the waste tire is based on the tires sales performance. The sale of the tires in Indonesia is growing and equal with the increment of the sales of car and motorcycle. Based on the data, the car passenger tire sales performance in Indonesia from January-October 2010 is 41,043,471 units, replacement is 8,515,841 units, production 41,001,300 units [*Asosiasi Perusahaan Ban Indonesia* (APBI) in 32]. The waste of the tire is increasing in every year. This is a big problem because the waste of tires cannot be easily processed by nature. Some alternative to re-process the tire waste are incineration cement, incineration, remanufacturing, reuse, material recycling, and landfilling [31].

Utilization of scrapped tire rubber in asphalt concrete mixtures is one of the alternatives for reducing environmental pollution and supporting Clean Development Mechanism (CDM) program. CDM is regarded as one of the most important internationally implemented market-based mechanisms to reduce carbon emissions [10]. Sustainable development of concrete by utilizing waste to replace natural resources generates positive impact to the nature especially for non-biodegradable waste such as waste tire rubber [33]. Waste tire rubber was categorized as non-biodegradable waste because it was tire was design to have high durability to weathering and heat. Hence, it offers a lot of potential to be recycled or reused [34]. With the number of waste tire is increasing in every year, the use of scrapped tire rubber in asphalt concrete mixtures is very potential to promising for application in Indonesia or any other developing countries.

Based on the Marshall Test of samples the optimum asphalt contents obtained from this study is as follows: optimum asphalt content of $AC_{Standard}$ mixture is 6.76%, $AC_{Scrapped\text{-}tire\ 50\%}$ mixture is 7.04%, and of $AC_{Scrapped\text{-}tire\ 100\%}$ mixture is 6.25%. This result is similar to the research of Kurniati [16] and Novianto [35]. The optimum asphalt content with scrapped rubber tires in Asphalt Concrete (AC) mixtures is larger than that of natural stone. The value of optimum asphalt content for the mixture using scrapped rubber tires is 7.40%, whereas optimum asphalt content values for the mixture using natural stone is 7.10% [16]. Mixture with 50% aggregate substitute in fraction No. 50 has the highest resistance to water (93.09%) when compared to the mixture with 100% replacement of aggregate at fraction No. 50 (91.81%) and the mixture without any scrap tires (91.07%). Asphalt cement mixture with 50% and 100% replacement of aggregate at fraction No. 50 has a smaller tensile resistance when compared with a mixture without tires ($AC_{Standard}$). The use of scrapped rubber tires in asphalt concrete mixtures can improve the resistance to permanent deformation due to ruts [16]. The addition of scrapped rubber tires up to ±3% in the asphalt concrete mixture; produce a better performance than the concrete mixture asphalt standard to the conditions of temperature above 30°C [35]. The use of scrapped tires rubber for asphalt pavement material is suitable for use in hot climates [13].

Based on the Marshall test, Voids in Mixture (VIM) value of optimum asphalt content $AC_{Standard}$ mixture is 4.39% while for the $AC_{Scrapped\text{-}tire\ 50\%}$ mixture is 4.09% and for the $AC_{Scrapped\text{-}tire\ 100\%}$ mixture is 3.97%. The differences of VIM value are due to differences in levels of asphalt content and density values. It is very important to maintain the value of VIM [2]. The VIM value required is between 3.50% - 5.50% for AC mixture [11, 36]. The mixture in that range or interval is not susceptible to melting, flowing, and plastic deformation [35]. The stability value of optimum asphalt content to $AC_{Standard}$ is 1,358.5 kg while for the $AC_{Scrapped\text{-}tire\ 50\%}$ mixture is 1,180 kg and for the $AC_{Scrapped\text{-}tire\ 100\%}$ mixture is 1,391 kg. Crushed stone aggregate has abrasion and level of hardness better than one of scrapped rubber tire. In addition, the scrapped rubber tire is round, easily broken, and unfavorable aggregate interlocking making stability of $AC_{Scrapped\text{-}tire\ 50\%}$ mixture lower than $AC_{Standard}$. The minimum requirement for stability value of AC mixture is 1,000 kg [11, 36], so that three different types of asphalt concrete mixtures preoccupied the specified requirements for AC mixture.

The Marshall flow test of $AC_{Standard}$ optimum asphalt content is 3.65 mm while the $AC_{Scrapped\text{-}tire\ 50\%}$ mixture is 3.20 mm and for the $AC_{Scrapped\text{-}tire\ 100\%}$ mixture is 3.33 mm. Scrapped tire rubber is not porous, crushed stone aggregate absorbs the asphalt but scrapped tire rubber does. A specification of AC mixture for flow value is at minimum 3 mm [11, 36]. The Marshall Quotient values for $AC_{Standard}$ mixture is 371.15 kg/mm, $AC_{Scrapped\text{-}tire\ 50\%}$ mixture is 369.2 kg/mm and for the $AC_{Scrapped\text{-}tire\ 100\%}$ mixture is 425.8 kg/mm. $AC_{Standard}$ mixture is more rigid than the $AC_{Scrapped\text{-}tire\ 50\%}$ mixture, but still fulfills the specification of Marshall Quotient values AC (minimum 250 kg/mm) [27]. In generally, based on the Marshall test characteristics the use of scrapped tire rubber is acceptable as a partial replacement of aggregate in asphalt concrete mixtures for road surface layers.

4.0 CONCLUSION

Conclusions of this study are as follows:

a) The optimum asphalt content value of $AC_{Scrapped\text{-}tire\ 50\%}$ mixture is 7.04%, larger than the optimum asphalt content $AC_{Standard}$ mixture is 6.76% and $AC_{Scrapped\text{-}tire\ 100\%}$ mixture is 6.25%.
b) The Marshall test characteristic of $AC_{Standard}$ mixture are larger than the value of $AC_{Scrapped\text{-}tire}$ mixture for Voids in Mixture (VIM) value and flow value.
c) Scrapped tire rubber can be used as an alternative material to replace fine aggregate in asphalt concrete mixtures for reducing environmental pollution and supporting Clean Development Mechanism (CDM) program.

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