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Evaluating the effect of using shredded waste tire in the asphalt concrete-binder coarse on Marshall parameters

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Abstract
Shredded Waste Tires are industrial materials that can be used in the asphalt mixture. The use of tires increases every day, considering the number of vehicles that grow from year to year. Using used tires is highly recommended for efforts to reduce waste that will harm the environment. The research aims to see the effect of adding shredded tires in a pavement mixture based on Marshall Value. The AC-BC pavement layer is not directly in contact with wheel load. Still, it must have sufficient thickness and stiffness to minimise stress or strain from traffic loads continuously transferred from the top of the pavement. The most important characteristic of the AC-BC is its stability. The optimum asphalt content value in the AC-BC mixture is 6.81%, mixed with various shredded waste tires. The Asphalt Concrete-Binder Course blended with 1.5%, 3.5%, 5.5% and 7.5% of the various shredded waste tire. The optimum shredded tire content was obtained at 3.5%, with the stability value increased by 2.1% from 1581.98 to 1614.88 kg, with a flow value of 5.43 mm, and a Marshall Quotient value of 297.4 kg/mm.

Keywords:
AC-BC;
Marshall parameter;
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INTRODUCTION

Due to the volume and non-biodegradable behaviour of waste plastics and scrap tires, those wastes were hard to dispose of, which became an extremely challenging problem in Indonesia and worldwide. Disposing to landfills and stockpiles [1] is a temporary solution that can lead to various associated problems, such as air and water pollution. Moreover, using potential land and the occupation of large land space for waste might lead to land dearth [2].

Several efforts of reducing waste products by mixing or adding to the asphalt have been investigated by many researchers. For instance, Gondorukem rubber mixed with Porous Asphalt [3][4] and Styrofoam added HRS-Base [5].

Tire waste can be processed as a valuable material such as activated carbon. Active carbon derived from tire waste has a wide application, excluding being vulcanised as a new tire. It can be used for adsorbent, energy storage applications like batteries and fuel cells [6].

Asphalt matrix and tyre rubber have differences in chemical as well as physical features. Before mixing with asphalt, the tyre has to be modified chemically or physically, such as grind or shred the tyres before being applied to the pavement [7]. The addition of shredded waste tires increased both the angle of internal friction and the shear strength of the sands [8][9]. Shredded tires were passed through US sieve size #4 and mixed with three different grains of sand with varying gradations.

The addition of shredded waste tires that passed through US sieve size #4 increased both the angle of internal friction and the shear strength of the sands [8][9]. However, it also decreased the compressive strength, flexural strength, and bending capacity of concrete as the rubber content increased.

Shredded tires mixed with three different types of sands with varying gradations in different percentages, i.e., 5%, 10% and 15% in volume. Then it resulted in the failure deflection of rubber concrete being greater than that of plain concrete, which indicates the ability of rubber concrete to resist greater deformation than ordinary concrete [10].

Hence, it is more suitable for architectural uses, low-strength concrete purposes such as sidewalks, driveways, particular road construction, and crash barriers around bridges and related structures [11].

Deconstructed tyres between the course of the pavement were developed and tested of anti-reflective cracking mats, and it can reduce the effect caused by fatigue cracking processes [12].

This recycled waste management can be innovative research since it can save the environment from the inevitable heaps. Since these used tires are mainly made of rubber, and by its nature can increase adhesion. It has been widely used as an additive to asphalt. Hence this research tries to use this waste tire as a pavement additive.

Tyres consist of solid rubber or polymer materials coupled with synthetic fibres and solid steel. So, tires have unique properties such as having high tensile strength, flexibility, and high shift resistance [8]. The recycled tyre rubber built with recycled aggregates containing steel slag in the production of asphalt concrete for road pavements reveals the better performance: a significant increase in stiffness at higher temperatures and a decrease in permanent deformation (fatigue and rutting) [13].

Various waste tyres can be used as additives to asphalt mixtures, such as crumb rubber tires or shredded tires [14]. In this investigation, a shredded tire is used to be added to the mixture. Shredded waste tyres are made from waste tyres categorised as one of the industrial materials that can be used as an additive to the asphalt mixture.

Despite the difficulties in creating the homogenous shredded tyre and asphalt mixture, using used tyres in pavement mixtures is expected to be effective in avoiding pollution and environmentally friendly.

Hence, this investigation aims to add a shredded waste tire as a partial replacement for asphalt on the Marshall value of the Asphalt Concrete-Binder Course mixture.

MATERIALS AND METHODS

Asphalt Concrete-Binder Course

Asphalt Concrete-Binder Course is a layer of pavement below the wear layer (wearing course) or above the foundation layer (base course). Even though the AC-BC layer is not directly exposed to the weather, it must have sufficient thickness and stiffness to minimise stress or strain from traffic loads that are continuously transferred to the underlying layer grades. The most important characteristic of the AC-BC coating is its stability [15][16]

The materials for the research consist of coarse aggregates, fine aggregates, filler and bitumen. Meanwhile, the crushed stone dust is chosen for the mineral fillers. Those materials were collected from a local quarry in Padang, West Sumatera.

The dry sieving was carried out in line with General Specifications of Highways in 2018 [17]. The sieve analysis of AC-BC gradation aggregate for this case study, in conjunction with their upper and lower limits set by ASTM-C136-06, is presented in Table 1. The aggregate must be examined in the laboratory to determine its characteristics before mixing it with other materials for road pavements.

The selection of the type of aggregate is an important thing in the asphalt mixture because it relates to the stability of the road construction. It can be classified and identified according to its size, cleanliness, strength, hardness, grain shape, surface texture, porosity, composition of its constituent, and adhesion to asphalt to determine the appropriate aggregate.

The technical requirements for coarse aggregate and fine aggregate, as seen in Table 2, are based on the Specifications of the Directorate General of Highways 2018 [17].

Table 1. Gradation of Aggregate

Sieve Size		Percentage passing (%)	
ASTM	(mm)	range	result
1"	25	100	100
3/4"	19	90 - 100	100
1/2"	12.5	75 - 90	89.662
3/8"	9.5	66 - 82	71.588
No.4	4.75	46 - 64	44.857
No.8	2.36	30 - 49	26.442
No.16	1.18	18 - 38	17.972
No.30	0.6	12 - 28	12.542
No.50	0.3	7 - 20	7.927
No.100	0.15	5 - 13	1.896
No.200	0.075	4 - 8	0.064
pan	0	0	0.00

Table 2. Properties of Aggregate [17]

No	Properties of Aggregate	Test Result	Standard requirement
1	Coarse Aggregate		
	Dry bulk density	2.611	
	Bulk density of dry saturated surface (SSD Condition)	2.654	
	Apparent Density	2.727	
	Absorption	1.632	< 3 %
2	Fine Aggregate		
	Dry bulk density	2.460	
	Bulk density of dry saturated surface (SSD Condition)	2.532	
	Apparent Density	2.650	
	Absorption	2.923	< 3 %
3	Aggregate Density	2.545	> 2.5
4	Bulk Density		
	Bulk density (loose)	1.524	> 1
	Bulk density (Shaking)	1.610	> 1
	Bulk Density (Stubbing)	1.533	> 1
5	Weight Loss on Los Angeles machine (%)	25.604	< 30 %
6	Aggregate Impact Value (%)	24.317	< 30 %
7	Aggregate Crushing Value (%)	4.531	< 30 %
8	Aggregate adhesion to asphalt (%)	≥ 95	> 95 %

Table 3. Properties of Bitumen

No.	Properties of Bitumen	Standard Test Method	Standard requirement	Test Result
1	Penetration (0.1 mm)	SNI 2456:2011	60-70	70
2	Burnt Point (°C)	SNI 2433:2011	≥ 300	325
3	Softening Point (°C)	SNI 2434:2011	> 48	55
4	Ductility (cm)	SNI 2432:2011	> 100	>100
5	Flash Point (°C)	SNI 2433:2011	> 232	256
6	Solubility in Trichlorethylene (%)	AASHTO T44-14	> 99	>99
7	Specific Gravity gr/cc	SNI 2441:2011	> 1,0	1.006
8	Weight Loss (%)	SNI 06-2440-1991	< 0.8%	0.76%

Meanwhile, the properties of the 60/70 penetration grade bitumen can be seen in Table 3.

Several tests were performed on bitumen to obtain the properties such as the penetration, burnt and flash point, softening point, ductility, specific gravity, solubility in Trichlorethylene (%) and weight loss, as shown in Table 3. The test is based on the specifications from the Directorate General of Highways 2018 Revision 2 at Division no. 6 [17]. Meanwhile, the required value for the Marshall parameter for AC-BC pavement is presented in Table 4.

Table 4. Marshall Requirement for AC-BC pavement [17]

No.	Parameter	Requirement
1	Stability	≥ 800 kg
2	Flow	2 mm – 4 mm
3	Void in Mix (VIM)	3 % – 5 %
4	Voids in the Mineral Aggregate (VMA)	> 14%
5	Voids Filled with Asphalt (VFA)	> 65%
6	Marshall Quotient (MQ)	> 250 kg/mm

Shredded Waste Tire

Shredded waste tyre collected from a local warehouse. Used motorcycle tyres were chosen for this study due to their abundant availability and easier to shred through the crushing process and passing the sieve no. 80 mesh sieve (diameter of 0.125 mm) [18][19].

As a partial replacement of the bitumen content mixed into the asphalt mixture, the shredded waste tire was expected to provide better resistance to high temperatures and traffic loads than asphalt without additional mixtures [20]. Waste tyre powder is a three-dimensional network or a cross-linked product of natural rubber and synthetic rubber reinforced with carbon black, which absorbs dilute oil from asphalt cement that can undergo swelling and softening of used tire powder [20][21].

In order to yield the easier and more homogeneous mixture, the tyre was shredded till passing the #80 sieve size. Tyre rubber consists of 44.32% natural rubber, and a mixture of 15.24% butadiene, 1.85% aromatic oil, 30.47% carbon black element, 1.07% stearic acid, 0.83% antioxidant, and sulphur 1.42% [22].

Moreover, the supporting materials in the tyres that increase the strength are carbon, silica, sulphur, accelerators, activators, antioxidants and textiles [23].

Marshall Parameters

The Marshall test apparatus is equipped with a proving ring with a capacity of 5000 pounds or 2500 kg that follow the procedures in the road material inspection manual (MPBJ) PC – 0201 - 76 or AASHTO T 245 - 74 or ASTM D 1559 - 62 T. The test works by applying pressure to the test object until reaching the limit of the load that the test object can bear. The strength value is seen on the dial needle in the Marshall test instrument. There are two dials, each of which has a different function, namely a dial that shows the value of the resistance (stability) and flow of the test object [24][25].

When the test object reaches its resistance limit, the needle on the stability dial will stop for a moment and rotate back in the opposite direction. The resistance limit value of the test object is when the needle stops before turning back around. The reading of this value also coincides with the reading of the flow value limit indicated by the second dial. The greater the value indicated by the dial, the stronger and more stable the asphalt mixture.

RESULTS AND DISCUSSION

Determination Calculated Bitumen Content

Bitumen requirement in pavement mixture is directly determined by the surface area of the aggregates in the mix, which affects the asphalt film thickness and the flow characteristics. Therefore, the surface area of aggregate combination in AC-BC is calculated using the particular surface area based on percentage passing through some particular standard sieve sizes.

Determination of the calculated bitumen content was used the surface area method. The principle of this method is that all the amount of asphalt will cover the actual surface area of the aggregate to obtain high quality well, covered asphalt. This method can be used for materials that have various types of gradations.

The calculated optimum bitumen content is equal to 6.8% to see the amount of surface area of aggregate as seen in Table 5, that should be covered with asphalt [8]. Thus, the composition for each mixture is shown in Table 6.

Determination Optimum Bitumen Content

The performance of an asphalt concrete mixture was based on the determination of the correct proportion of aggregate and asphalt cement. To determine the optimum asphalt cement content to produce asphalt concrete mixtures with strength and durability properties that meet the standard specifications.

Table 5. Aggregate Surface Area

Sieve Size	Sieve passing (%)	Detained Sieve (%)	Each Fraction (%)	Surface area (mm^2)
1'	100	0.00	0.00	0.00
3/4"	100	0.00	0.00	0.00
1/2"	89.66	10.34	10.34	14.34
3/8"	71.59	28.41	18.07	58.67
#4	44.86	55.14	26.73	85.19
#8	26.44	73.56	18.42	116.74
#16	17.97	82.03	8.47	139.01
#30	12.54	87.46	5.43	197.48
#50	7.93	92.07	4.62	376.43
#100	1.90	98.10	6.03	1097.64
#200	0.064	99.95	1.83	333.42
PAN	0.000	100.00	0.064	39.36
			Total	2458.28

Table 6. Materials Composition

Asphalt Content (%)	Asphalt Weight (gr)	Coarse Agg (gr)	Medium Agg (gr)	Fine Agg (gr)
5.8	69.6	293.904	361.73	474.77
6.3	75.6	292.34	359.81	472.25
6.8	8160	290.78	357.88	469.73
7.3	87.6	289.22	355.97	467.21
7.8	93.6	287.66	354.05	464.69

There are fifteen samples prepared at five various bitumen content and three samples at each bitumen content of 5.8%, 6.3%, 6.8%, 7.3% and 7.8%. The result of Marshall testing for optimum bitumen content determination are presented in Figure 1.

As shown in Figure 1, the optimum bitumen content of bituminous mixtures is determined based on the average values that satisfy the requirements for Marshall stability, Marshall flow, VIM, VMA, VFB and MQ.

Hence, the optimum bitumen content (OBC) is 6.81%, and this value of OBC will be used to mix AC-BC pavement mixture with shredded tire addition.

Determination Optimum Shredded Waste Tire Content

The AC-BC binder mixtures were prepared by mixing with various shredded tires 0%, 1.5%, 3.5%, 5.5%, and 7.5% (by weight of optimum bitumen content). The weight of each material composition was used 6.81% optimum bitumen content obtained previously. The composition of each sample is presented in Table 7.

The 1.25mm (#80) of sieve size shredded waste tire was mixed with aggregates to find the optimum percentage by conducting a Marshall test to obtain the specified strength.

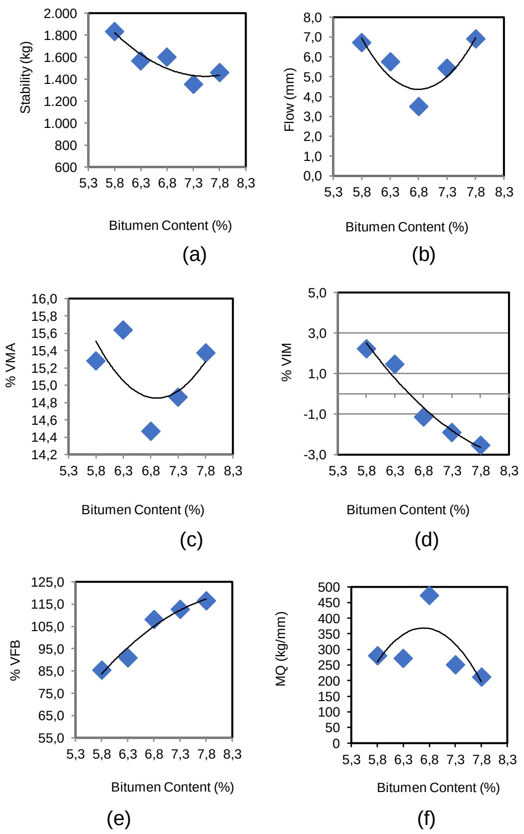

Figure 1. Marshall test results for optimum bitumen content determination

Table 7. Material Compositions

Component	Weight of each material				
Shredded Tire Content (%)	0	1.5	3.5	5.5	7.5
Tire Crumb Weight (gr)	0.00	1.23	2.86	4.49	6.13
Asphalt Weight (gr)	81.71	80.48	78.85	77.21	75.58
Aggregate Weight (gr)	**1118.29**	**1118.29**	**1118.29**	**1118.29**	**1118.29**
Coarse Agg (gr)	290.76	290.76	290.76	290.76	290.76
Medium Agg (gr)	357.85	357.85	357.85	357.85	357.85
Fine Agg (gr)	469.68	469.68	469.68	469.68	469.68

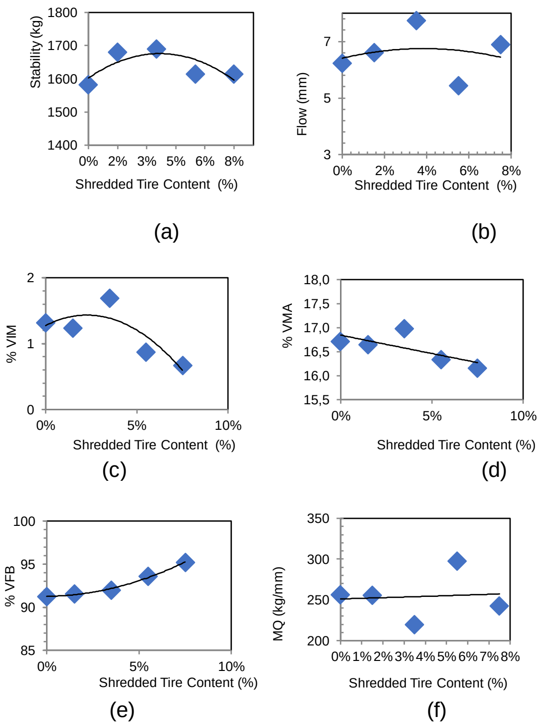

Figure 2. Marshall results for Optimum Shredded Tyre determination

The Marshall test results of AC-BC mixture with various percentages of shredded tires are shown in Figure 2.

As seen from Figure 2(a), the Marshall stability values increased significantly with increased shredded waste tyre-replaced bitumen content up to 5.5% but decreased simultaneously with 5.5% to 7.5%. The maximum Marshall stability was obtained as 1689.93 kg with 3.5% shredded waste tire-replaced bitumen. However, all the shredded waste tire specimens were higher stability values, above the standard requirement at 800 kg. This variation in Marshall stability could be because the increase in shredded waste tire content decreases the voids in the AC-BC, producing a well-packed mix. As a result, Marshall stability increased up to 3.5% modification. Beyond 3.5% of bitumen replacement, the contact between the coarse aggregate diminished, resulting in decreased Marshall stability.

While in Figure 2(b), Marshall flow values increased significantly with shredded waste tire content up to 3.5%, and then fluctuating decreased and increased as the shredded content increased. Increased Marshall flow values show that the replacement of shredded tires into conventional bitumen increased the flexibility of the pavement.

Hence, increasing the content decreased bitumen absorption at high temperatures, increasing the freely available bitumen in the void of the AC-BC mix. However, the Marshall stability and Marshall flow values met the requirements of heavy traffic roads according to General Specifications of Highways in 2018.

VMA values satisfied the required minimum values of 15% in terms of physical properties. However, VIM values were very low, less than 2% for all modifications, as seen in Figures 2(c) and Figure 2(d). Figure 2(e) shows an increase in the VFA value along with the increase in the use of shredded tires in the AC-BC mixture. The overall VFA values meet the required value which is more than 65%. Moreover, the MQ value of the AC-BC mixture, as seen in Figure 2(f) were, also fluctuating. The highest MQ value was obtained at shredded tire content of 5.5% with a value of 297.248 kg/mm, meanwhile the lowest value was at 3.5% at 219.117 kg/mm. Fortunately, the MQ value of the AC-BC mixture with shredded tire has met the specified requirements.

Thus, the optimum shredded waste tire content was chosen at 5.5%, with the stability value of 1614.88 kg, a flow value of 5.43 mm, and a Marshall Quotient value of 297.4 kg/mm. However, even though the 3.5% shredded waste tire content had the highest stability, it also has higher flow, resulting in a very low result of Marshall Quotient for the AC-BC pavement.

CONCLUSION

Based on the investigation results, with the optimum bitumen content of 6.81% mixed with various shredded waste tires, it can be concluded that Marshall parameter values for the AC-BC mixture generally meet the General Specifications of Highway 2018 Revision 2. As the value of the shredded waste tire content increases in the pavement mixture, the stability value also increases. For example, the modified AC-BC pavement with 5.5% shredded tire wastes showed an increase of Marshall Stability value by 2.1% from 1581.798 kg to 1614.88 kg, with 5.433 mm of flow.

The flow value without shredded tyres was 3.5 mm for the maximum stability value. Moreover, the use of shredded tyres in the mixture resulted in a higher flow value to achieve the maximum stability value, which is 5.43 mm. Meanwhile, the MQ value using shredded tyres decreased from 370 kg/mm to 297.4 kg/mm, but this value was still above the minimum requirement for an AC-BC pavement mix. VMA values satisfied the required minimum values of 15%. However, VIM values were very low, less than 2%.

Hence, it can be concluded that the addition of shredded waste tire material on the AC-BC can be recommended in terms of higher stability lower void. Thus, it can be categorised as a pavement resistant to oxidation, reducing the waste products to the landfill.

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