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Effect of Marshall Characteristics with The Addition of *Polyethylene Terephthalate* (PET) Waste as a *Filler* Mixture in Asphalt

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ABSTRACT
Asphalt pavement is one of the main elements of transportation infrastructure. However, asphalt pavements often suffer from damage such as cracking, plastic deformation, and peeling due to the influence of traffic loads and extreme temperature changes. With the extensive use of plastics in daily life leading to an increase in plastic waste, which has become one of the serious problems in Indonesia, an alternative solution is needed to address this issue. By modifying the asphalt filler using Polyethylene Terephthalate (PET) waste, the AC-WC asphalt layer is one way to increase the stability of the road structure. The purpose of this study is to determine the comparison of the value of Marshall characteristics in the AC-WC layer with the addition of Polyethylene Terephthalate (PET) waste filler fixed at 7%, and Polyethylene Terephthalate (PET) waste varying by 6%, 6.5%, 7%, 7.5%, and 8%, and to analyze the effect of adding PET plastic waste on the value of Marshall characteristics as a mixture of asphalt filler in the AC-WC layer. The method used in this research is the experimental method, using a control variable of 5.3% asphalt content with a fixed PET combination of 7%. Based on the results of the study, the addition of PET waste in the AC-WC asphalt mixture influences Marshall characteristics, as evidenced by changes in Stability, Flow, VIM, VFM, VFB, and Marshall Quotient values. It can be concluded that with increasing levels of PET waste variation, there is an increase in Stability and VFB values, but a decrease in VIM and VMA values. This is because the addition of PET waste has a positive effect on stability and reduces air voids in the AC-WC layer.
Keyword: AC-WC Laston, Marshall Characteristics, Polyethylene Terephthalate (PET)

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INTRODUCTION

Asphalt pavement is one of the main elements of transportation infrastructure that can withstand heavy traffic loads and diverse environmental conditions. However, asphalt pavements often suffer damage such as cracking, plastic deformation, and peeling due to the influence of traffic loads and extreme temperature changes. Therefore, it is necessary to develop asphalt mixtures with better resistance to loads and environmental factors (Aletba et al., 2021; Alfayez et al., 2020; Gong et al., 2023; Hao et al., 2024; Liu et al., 2020).

Highway pavement is a structural element in road infrastructure reinforced through several construction layers designed with thickness, strength, stiffness, and durability considerations. It ensures sufficient stability to efficiently and safely transmit traffic load to the subgrade. This layer, located between the vehicle load and the subgrade, supports smooth traffic flow and is expected to maintain optimal performance without significant damage during its service life (Guo et al., 2022; Li et al., 2019; Maduabuchukwu Nwakaire et al., 2020; Pourgholamali et al., 2023; Tang et al., 2022).

Waste is a cultural problem significantly impacting people's lives. The high volume of waste in an area typically correlates with its population size. As population and income increase, lifestyles become more consumptive, producing large amounts of waste. The waste problem in Indonesia is also caused by various factors, including socio-economic conditions, cultural aspects, and the lack of government and community awareness in waste management (Budsaereechai et al., 2019; El-Sayed, 2023; Enggar et al., 2023; Kartika, 2022; Latha et al., 2023; Wahyudi et al., 2018).

The use of plastic goods has become a necessity in human life and a cultural norm. This is because plastics have diverse functions that fulfill community needs. Especially with advances in technology, many plastics have been produced with various shapes, sizes, colors, and attractive motifs (Khoirunnisa & Kadarohman, 2022).

The large amount of plastic use in daily life causes an increase in plastic waste, which has become a serious problem in Indonesia, including plastic waste such as Polyethylene Terephthalate (PET). Therefore, alternatives are needed to address this issue. With rising plastic waste and rapid construction technology advancement, utilizing PET plastic waste in asphalt mixtures reduces plastic waste and can improve the mechanical properties of asphalt.

To address plastic waste, innovations such as reducing plastic use or effective plastic waste management are needed. One method is using plastic as a mixture in asphalt filler. Incorporating plastic waste in asphalt filler mixtures can increase pavement strength (Alwie et al., 2020).

The addition of PET waste to asphalt mixtures aims to improve mixture characteristics, especially parameters measured by Marshall tests such as Stability, Flow, and the Marshall Quotient (MQ). Research by Alwi et al. (2020) shows that adding PET at levels of 1% to 3% in the AC-WC Laston mixture using the dry process increases stability and MQ, while flow and Voids in Mix (VIM) do not meet standards. The optimal PET content was 2%, meeting the 2018 General Classification of Roads and Bridges requirements. Simangunsong et al. (2021) show that adding 6% PET increases residual Marshall stability after soaking up to 90.30%, indicating good resistance to damage from water, temperature, and weather.

Modifying the asphalt filler using Polyethylene Terephthalate (PET) waste in the AC-WC layer is a way to improve road structure stability. Asphalt is a natural, nonrenewable material, so filler modification is necessary. Using PET waste is an alternative to reduce natural material consumption and addresses the growing problem of PET waste, which is not easily decomposed in the environment.

Previous studies (Alwi et al., 2020) demonstrated that adding 1–3% PET waste to AC-WC Laston mixtures via the dry process improved stability and MQ, with 2% PET being optimal per 2018 road standards, although flow and VIM did not meet standards. Simangunsong et al. (2021) found that 6% PET increased residual Marshall stability after soaking to 90.30%, indicating enhanced resistance to water, temperature, and weather-related damage. However, both studies focused mainly on limited PET content levels, not comprehensively comparing fixed versus varied PET filler compositions, leaving a gap in understanding how variation patterns influence multiple Marshall characteristics simultaneously.

The purpose of this study is to compare Marshall characteristic values in the AC-WC layer with fixed and varied Polyethylene Terephthalate (PET) waste filler levels and analyze the effect of adding PET plastic waste on Marshall characteristics as an asphalt filler mixture in the AC-WC layer. This study aims to provide empirical evidence for optimal PET utilization in asphalt mixtures, contributing to improved pavement performance and sustainable waste management practices.

METHOD

The method used in this research is the experimental method, namely conducting experiments on AC - WC asphalt mixture test objects with the addition of *Polyethylene Terephthalate* (PET) waste as a *filler* mixture. This research was conducted in the laboratory of PT Perwita Karya Kontruksi, Beber sub- district, Cirebon district.

Number of Samples/Test Items

Table 1. Making Test Objects Planning Optimum Asphalt Content

Asphalt Content (%)	Number of Test Objects
4,5%	3
5%	3
5,5%	3
6%	3
6,5%	3
Total	**15 Test Objects**

Table 2: Making of KAO (5.3%) Test Objects+ PET 7%

Asphalt Content (%)	Number of Test Objects
5,3%	3
Total	**3 Test Objects**

Table 3. Asphalt Preparation with PET Addition

KAO+ PET Variation (%)	Number of Test Objects
KAO+ 6%	3
KAO+ 6.5%	3
KAO+ 7%	3
KAO+ 7.5%	3
KAO+ 8%	3
Total	**15 Test Objects**

Research Flowchart

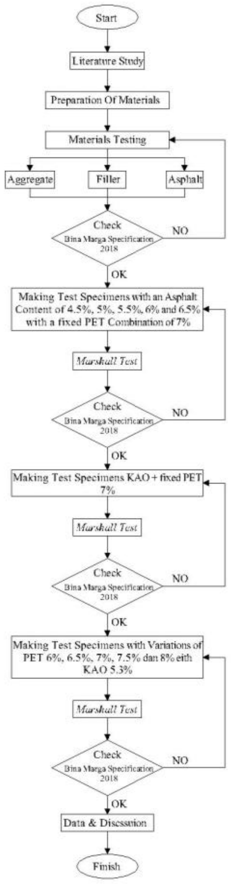

Figure 1. Research Flowchart

RESULTS AND DISCUSSION

Based on the objectives of this study, namely to determine the effect of Marshall Characteristics with the addition of Polyethyelene Terepthalate (PET) waste as filler in asphalt. Research data obtained from experimental results in the laboratory. The results of the data are processed and displayed in the form of tables and graphs. The following shows the data analysis table and graph: MATERIAL GRADATION

a. Coarse Aggregate analysis results

The data obtained from these test results are presented in Table 4.

Table 4. Analysis of coarse aggregate ¾ (Matrial Coarse Agg)

Sieve Size		Retained Weight	Cumulative Retained Weight	Sieve Pass	Retained Weight	Cumulative Retained Weight	Sieve Pass	Average Sieve Passage
		(Gram)	%	%	(Gram)	%	%	
3/4 "	19.0 mm	0,0	0,00	100,00	0,0	0,00	100,00	100,00
1/2 "	12.7 mm	3736	91,84	8,16	3206	89,06	10,94	9,55
3/8 "	9.53 mm	4033	99,14	0,86	3579	99,42	0,58	0,72
# 4	4.75 mm	4055	99,68	0,32	3591	99,75	0,25	0,28
# 8	2.36 mm							
# 16	1.18 mm							
# 30	0.60 mm							
# 50	0.30 mm							
# 100	0.15 mm							
# 200	0.075 mm							
Sample Weight of Sample X= 4068.0 Grams					**Sample Weight Y= 3600.0 Grams**			

The results of sieve analysis of coarse aggregates, for example Cirebon, show that sample X at sieve dia. 9.53 mm has a retained coarse aggregate percentage of 99.14%, a passing coarse aggregate percentage of 0.86%. In sample Y of sieve dia. 9.53 mm, the percentage of retained coarse aggregate amounted to 99.42%, and the percentage of passing coarse aggregate amounted to 0.58%, the average passing sieve of samples X and Y was 0.72%. In the AC - WC mix composition, 8% coarse aggregate was used, with a percentage composition value of 0.06%.

b. Medium Aggregate Analysis Results

The data obtained from these test results are presented in Table 5.

Table 5. Medium Aggregate ½ (Material Medium Agg

SIEVE SIZE	Retaine d Weight	Cumulat ive Retained Weight	Sieve Pass	Retaine d Weight	Cumulat ive Retained Weight	Siev e Pass	Average Sieve Passage

		(Gram)	%	%	(Gram)	%	%	
3/4 "	19.0 mm	0	0	100	0	0	100	100
1/2 "	12.7 mm	0,0	0,0	100,00	0,0	0,00	100,00	100,00
3/8 "	9.53 mm	875	31,50	68,50	893	32,41	67,59	68,04
# 4	4.75 mm	2382	85,75	14,25	2409	87,44	12,56	13,41
# 8	2.36 mm	2704	97,34	2,66	2704	98,15	1,85	2,26
# 16	1.18 mm	2725	98,09	1,91	2725	98,91	1,09	1,50
#30	0.60 mm	2728	98,20	1,80	2730	99,09	0,91	1,35
#50	0.30 mm							
#100	0.15 mm							
#200	0.075 mm							
Sample Weight Sample X= 2778.0 Grams					**Sample Weight Y= 2755.0 Grams**			

c. Fine Aggregate Analysis Results

The data obtained from these test results are presented in Table 6.

Table 6. ***Fine Aggregate (Material Fine Agg)***

SIEVE SIZE		**Retaine d Weight**	**Cumulative Retained Weight**	**Sieve Pass**	**Retaine d Weight**	**Cumulative Retained Weight**	**Sieve Pass**	**Average Sieve Passage**
		(Gram)	**%**	**%**	**(Gram)**	**%**	**%**	
3/4 "	19.0 mm	0	0	100	0	0	100	100
1/2 "	12.7 mm	0	0	100	0	0,00	100	100
3/8 "	9.53 mm	0,0	0	100	0,0	0,00	100	100
# 4	4.75 mm	0,0	0	100,00	0,0	0,00	100,00	100,00
# 8	2.36 mm	236,5	23,65	76,35	263,7	21,98	78,03	77,19
# 16	1.18 mm	430,2	43,02	56,98	512,8	42,73	57,27	57,12
# 30	0.60 mm	636,8	63,68	36,32	737,1	61,43	38,58	37,45
# 50	0.30 mm	742,2	74,22	25,78	886,3	73,86	26,14	25,96
# 100	0.15 mm	822,6	82,26	17,74	992,4	82,70	17,30	17,52
# 200	0.075 mm	907,7	90,77	9,23	1089,1	90,76	9,24	9,24
Sample Weight X= 1000.0 Grams					**Sample Weight Y= 1200.0 Grams**			

The results of the sieve analysis of fine aggregates, for example Cirebon, show that sample X at sieve dia. 9.53 mm has a retained fine aggregate percentage of 0%, a passing fine aggregate percentage of 100%. In sample Y of sieve dia. 9.53 mm, the percentage of retained fine aggregate was 0%, and the percentage of passing fine aggregate was 100%, the average passing sieve of samples X and Y was 100%. In the AC - WC mix composition 56% fine aggregate was used, with a percentage composition value of 56%.

d. *Filler* Analysis Results

The data obtained from these test results are presented in Table 7.

Table 7. ***Filler (Fine Agg Material)***

SIEVE SIZE		Retaine d Weight	Cumulative Retained Weight	Sieve Pass	Retaine d Weight	Cumulative Retained Weight	Sieve Pass	Average Sieve Passage
		(Gram)	%	%	(Gram)	%	%	
#4	4.75 mm							
#8	2.36 mm							
#16	1.18 mm							
#30	0.60 mm	0,0	100,00	0,0	0	100,00	100,00	
#50	0.30 mm	0,0	0	100,00	0,0	0	100,00	100,00
#100	0.15 mm	4,1	0,63	99,37	3,5	0,49	99,51	99,44
#200	0.075 mm	64,7	9,88	90,12	72,85	10,25	89,75	98,93
Sample Weight of Sample X= 655.0 Grams					**Sample Y Weight= 710.0 Grams**			

The results of the *filler* sieve analysis, for example Cirebon, show that sample X on a sieve dia. 9.53 mm has a retained *filler* percentage of 0%, the percentage of *filler* that passes is 100%. In sample Y sieve dia. 9.53 mm, the percentage of retained filler is 0%, and the percentage of *filler* that passes is 100%, the average obtained passes the sieve from samples X and Y by 100%. In the composition of the AC - WC mixture, 1% *filler* is used, with a percentage composition value of 1%.

e. Planning Gradation of AC - WC Mixture

Based on the results of the analysis that has been carried out, the AC - WC mixture gradation planning is obtained with the following total camp calculations

Total Mix = Σ Percentage Mix composition
= 1.00%+ 56.00%+ 23.82%+ 0.06%
= 80,87 %

From the AC - WC mixture gradation planning data above, it can be presented in the figure 2.

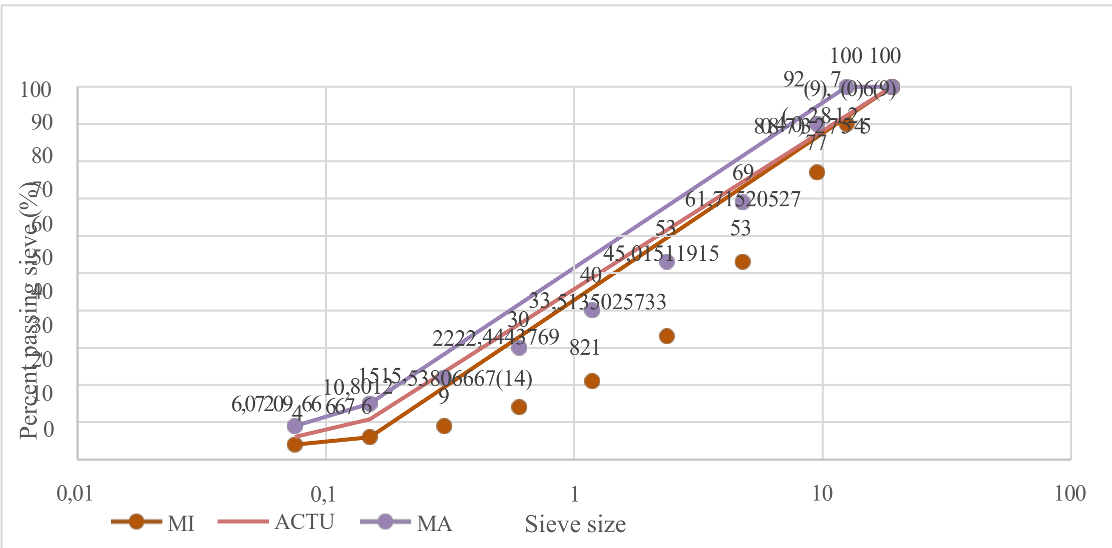

Figure 2. Planning Gradation of AC - WC Mixture

f. **Planning Of Centerline Asphalt Content**

According to Depkimpraswil Specifications 2002, the determination of the center asphalt content uses the following formula:

Pb= 0.035 (%CA) + 0.045 (%FA) + 0.18 (Filler)+ K

Description:

Pb = Center Asphalt Content.

CA = Retained Coarse Aggregate Sieve no.4

FA = Fine Aggregate Passes Sieve No. 4 and Retained Sieve No. 200 Filler

= Minimum 75% filler material that passes sieve No. 200

K = Constant with a value of 0.5 - 1.0 for san laston 2.0 - 3.0 for AC laston - WC K value taken with a value of 0.75

Pb = 0.035 (55%) + 0.045 (51.1%) + 0.18 (6.07%) + 0.5

= 5,82

The center asphalt content (Pb) value obtained from the calculation is 5.82%. This study used 5 levels of asphalt variations of 4.5%, 5%, 5.5%, 6%, and 6.5% with a fixed PET combination of 7%.

MARSHALL TESTING RESULTS

Recapitulation of Marshall Test Results Variation of Asphalt Content with 7% Fixed PET combination Table 8.

Table 8. Recapitulation of Marshall Testing Results KAO with a combination of PET Fixed 7%

No.	Parameters Unit	Asphalt Content (%)	Terms

			4,5	5	5,5	6	6,5	
1	Stability	kg	1049,1	1129,6	1266,8	1225,7	1189,1	Min 1,000
2	Flow	mm	2,98	2,87	2,89	3,21	3,26	Min 2.0 - max 4.0
3	VIM	%	7,12	5,02	3,20	2,26	1,37	Min 3.0 - max 5.0
4	VMA	%	15,41	14,58	14,01	14,24	14,53	Min 15
5	VFB	%	53,86	65,51	77,14	84,15	90,55	Min 65
6	MQ	kg/mm	352,63	393,41	438,97	383,35	365,45	

Based on the results of the experiments that have been carried out, it shows that the stability value increases with the addition of asphalt content until it reaches 5.5%, which is 1266.8kg. After that, the stability value began to decrease at 6% (1225.7kg) and 6.5% (1189.1kg) asphalt content. This shows that increasing the asphalt content with a fixed PET combination of 7% can increase the stability of the mixture so that it becomes denser, because the asphalt helps bind the aggregate well. And it can also be seen that the *flow* test shows that the *flow* value increases at first, but when the asphalt content is at 6.5% it continues to increase beyond the maximum limit of the 2018 Binamarga Specifications. This shows that the higher the asphalt content, the mixture becomes more plastic or soft, so the deformation value *(flow)* increases.

The VIM value in the test results above shows that the higher the percentage of asphalt, the VIM value decreases. This decrease is quite significant, from 7.11% at 4.5% asphalt content to 1.37% at 6.5% asphalt content. This shows that increasing the asphalt content reduces the air voids in the mixture. In the VMA value in the data above, it shows that the VMA value at 4.5% asphalt content is 15.41%. When the asphalt content was increased to 5% and 5.5%, the VMA value decreased to 14.58% and reached the lowest point of 14.01%. After that, at 6% and 6.5% asphalt content, the VMA value increased again to 14.24% and 14.53%. This shows that initially, the addition of asphalt fills the voids between aggregates, so the volume of voids between aggregates (VMA) decreases.

In the VFB value, it can be seen that the higher the asphalt content, the higher the VFB value. At 4.5 bitumen content, the VFB value was 53.86%, then gradually increased to 90.55% at 6.5% bitumen content. This shows that the more asphalt is added, the more aggregate voids are filled by the asphalt. It can be seen that, the MQ value decreased gradually to 383.4 at 6% asphalt content and 365.4 at 6.5% asphalt content. This isshows that increasing the asphalt content to the optimum point can increase the strength and stiffness of the mixture.

Based on the Marshall test results of asphalt variations with a combination of 7% fixed PET above, the KAO value can be determined which will be presented in **Figure 3.**

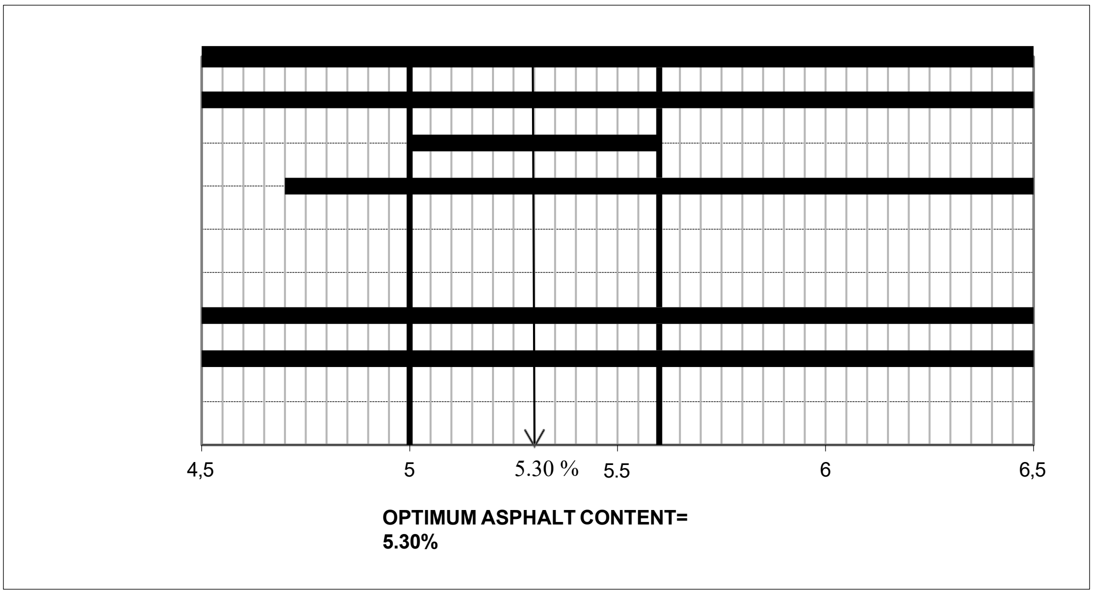

Figure 3. Optimum asphalt content

The KAO value is obtained from all Marshall parameters that meet the specifications with the following calculation.

$$KAO = \frac{5.5\% + 5\% + 5.5\%}{3}$$

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= 5,33%

The following Marshall characteristics with KAO values that meet the AC - WC asphalt mixture are presented in Table 9.

Table 9. Characteristic Marshall Value with KAO Value

No.	Parameters	Unit	Results with KAO Value	Terms	Description
1	Stability	kg	1170,8	Min 1,000	Meet
2	Flow	km	3,69	Min 2.0 - max 4.0	Fulfill
3	VIM	%	4,01	Min 3.0 - max 5.0	Meet
4	VMA	%	16,11	Min 15	Meet
5	VFB	%	75,09	Min 65	Meet
6	MQ	kg/mm	317,94		Meet

The determination of the optimum asphalt content (KAO) of 5.3% was carried out based on the results of a trial mix on an asphalt mixture with the addition of 7% PET plastic waste as a control variable. The test results showed that at 5.3% asphalt content, Marshall parameters such as stability, flow, VIM, VMA, and VFB were within the range that was in accordance with the provisions of the 2018 Bina Marga General Specifications, so the KAO was used for further testing of PET content variations.

Recapitulation of Marshall Testing Results KAO 5.3% with a combination of PET Content Variations

Based on the research data that has been conducted, the KAO value of 5.3% is obtained. Marshall testing of KAO 5.3% was carried out with a combination of variations in PET content, the following data is presented in the form of Table 10.

Table 10. Recapitulation of Marshall Testing Results KAO 5.3% with Combination of PET Content Variations

No.	Parameters	Unit	PET content (%)					Terms
			6	6,5	7	7,5	8	
1	Stability	kg	1042,7	1157,1	1170,8	1184,5	1193,6	Min 1,000
2	Flow	km	3,39	3,72	3,69	3,90	3,90	Min 2.0 - max 4.0
3	VIM	%	5,92	4,70	4,01	3,02	1,84	Min 3.0 - max 5.0
4	VMA	%	17,77	16,71	16,11	15,24	14,21	Min 15
5	VFB	%	66,72	71,90	75,09	80,42	87,09	Min 65
6	MQ	kg/mm	309,1	311,3	317,9	311,6	315,7	

Based on the research conducted, it can be seen that, at all levels of PET, the stability increased significantly above the minimum limit. This shows that the increasing PET content makes the mixture denser, because the bond between aggregate and asphalt binds each other well. In the melting test *(Flow)*, not all PET levels meet the requirements, it can be seen that with the increase in the addition of 7.5% and 8% PET levels for the AC-WC Laston asphalt mixture, the *Flow* value increases. This condition is caused by the greater the level of PET added, it shows that the asphalt mixture becomes more plastic and easily deformed so that it is easier to experience defornation due to the presence of added ingredients in the mixture that are added in excess.

In the VIM value for the AC-WC Laston asphalt mixture, it can be seen that as the level of PET variation increases, the VIM value decreases. This condition is caused by the more PET content added, it can increase the density of Marshall briquettes and air voids become less. It can be seen that at 8% PET content VMA value for Laston AC-WC asphalt mixture has decreased VMA value with a minimum limit of 15%. This condition is caused by the increasing PET content for the AC-WC Laston asphalt mixture, the less empty voids between aggregates are filled by asphalt. The more PET in the mixture, the denser the asphalt mixture.

Based on the data in Table 10. It can be seen that at all PET levels for the AC-WC Laston asphalt mixture, the VFB value increases with a minimum limit of 65%, besides that it can be seen that the VFB value increases with increasing PET levels and shows a significant change. This shows that the voids in the mixture are filled by asphalt. For the *Marshall Quetiont* value, all levels of PET in the MQ value increased significantly, but at levels of 7.5% and 8% the MQ value decreased. This condition is caused by the soft mixture which can be seen from the decreased stability because the aggregate does not lock, and the increased flow value causes rapid deformation.

CONCLUSION

The study found that increasing asphalt content with fixed PET levels initially improved Marshall Stability significantly, but stability decreased at higher asphalt contents of 6% and 6.5%. Flow values for all asphalt content variations complied with the 2018 Binamarga Specifications, while VIM, VMA, and VFB values met specifications only at specific asphalt percentages (5.5%, 4.5%, and 5%, respectively). Similarly, the Marshall Quotient increased notably but declined at 6% and 6.5% asphalt. For varied PET content, Stability consistently increased except at the highest PET level (8%), where Flow values failed to meet specifications. VFB values met standards across all PET levels, whereas VIM and VMA values met criteria only at certain PET percentages. Overall, the addition of PET waste positively enhanced Stability and reduced air voids (VIM and VMA), indicating improved asphalt mixture density in the AC-WC layer. Future research should explore long-term performance and durability of asphalt mixtures with varying PET contents under real-world traffic and environmental conditions, as well as optimize PET content to balance mechanical properties and specification compliance.

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