Jurnal Talenta Sipil

Vol 9, No 1 (2026): Februari, 607-615
Publisher by Program Studi Teknik Sipil
Fakultas Teknik Universitas Batanghari
ISSN 2615-1634 (Online), DOI 10.33087/talentasipil.v9i1.1214

Performance Evaluation of Marshall Mixed Asphalt Concrete-Binder Course (AC-BC) Using Modified LDPE Waste Asphalt with the Wet Method

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ARTICLE INFO
Keywords:
Waste Plastic; LDPE; AC-BC; Marshall Characteristic; Wet Mix

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Submitted: 26 November 2025
Revised: 22 Januari 2026
Accepted: 24 Januari 2026
Published: 04 Februari 2026

ABSTRACT
The critical issue of *Low-Density Polyethylene* (LDPE) plastic waste and the need to improve the durability of asphalt pavement underlie this study. Until now, studies on the utilization of plastic waste have focused more on surface layers (AC-WC), while in-depth research on binder layers (AC-BC) is still very limited. The objective of this study is to analyze the effect of LDPE plastic waste utilization on the Marshall characteristics of Asphalt Concrete-Binder Course (AC-BC) mixtures using the wet mix method. This study used an experimental method in the laboratory. After determining the control Optimum Asphalt Content (OAC) of 5.5%, Marshall testing was carried out on AC-BC mixtures with variations in LDPE addition (5%, 6%, and 7%) and variations in asphalt content (5%, 5.5%, 6%, and 6.5%). The results showed that the addition of LDPE increased the Marshall stability value. The highest stability value reached 2402 kg at an LDPE addition rate of 7% with an asphalt content of 5%. In addition, the addition of LDPE also increased the *Flow, Marshall Quotient* (MQ), *Voids in Mix* (VIM), *Voids Filled with Asphalt* (VFA), and *Voids in Mineral Aggregate* (VMA) values. In conclusion, the utilization of LDPE plastic waste has a significant effect on the mechanical and volumetric characteristics of AC-BC mixtures.

INTRODUCTION

The development of reliable, sustainable road infrastructure faces two significant challenges in the modern era: improving pavement durability under heavier traffic loads and adopting environmentally friendly practices. On the one hand, conventional asphalt pavements often experience premature degradation, such as permanent deformation (rutting) and fatigue cracking, due to exposure to climate and repetitive loads, resulting in high maintenance costs (Sukirman, 1999). On the other hand, the world is facing an unprecedented plastic pollution crisis. Indonesia, as one of the most significant contributors to marine plastic waste, is grappling with millions of tons of plastic waste Low-Density Polyethylene (LDPE), most of which comes from disposable bags(Handayasari et al., 2021). With the reported national recycling rate still very low, ranging from 10-15%(Badan Pusat Statistik, 2018), most of this waste ends up in landfills or pollutes the environment (Susanto et al., 2025). The initiative to utilize LDPE waste as an additive in road construction has emerged as a promising circular-economy solution offering the dual potential to reduce environmental pollution while improving pavement material quality(Meyrena & Amelia, 2020) .

Technically, polymer waste can be incorporated into asphalt mixtures using two methods: the dry method and the wet method(Fitriansyah et al., 2024). he dry method mixes plastic chips directly into hot aggregates, whereas the wet method, the focus of this study, involves directly modifying the binder. In the wet method, LDPE waste is melted and dispersed into hot bitumen at a specific temperature and duration to produce Polymer Modified Bitumen (PMB). Theoretically, this process allows for more intimate, homogeneous interactions between the polymer chains and the asphalt components (asphaltenes and maltenes)(Bualuang et al., 2025) . This conceptual basis suggests that the wet method has the potential to create superior composite binder materials, with a polymer network swollen within the asphalt matrix (Saputro et al., 2022). Previous studies have confirmed that polymer modification via wet methods can generally improve asphalt's rheological properties, such as increased softening point, decreased penetration, and increased viscosity, which collectively enhance resistance to deformation at high temperatures (Sudibyo et al., 2024).

However, an in-depth literature review reveals a significant research gap in the application of this technology. The main issue is that most existing studies on the utilization of LDPE waste, both wet and dry methods, tend to focus exclusively on surface layers, namely, Asphalt Concrete-Wearing Course (AC-WC). This focus on AC-WC is understandable, as this layer interacts directly with traffic and weather, making parameters such as skid resistance and wear resistance a priority. However, comprehensive research on the performance of LDPE modification in the structural layer below, namely the Asphalt Concrete-Binder Course (AC-BC), remains very limited. The implications of this gap are crucial, as the AC-BC layer plays a fundamental role in distributing loads from the surface to the foundation layers.

Failure or deformation occurring in the AC-BC layer will directly impact the structural integrity and service life of the pavement as a whole, regardless of the quality of the AC-WC layer above it.

The novelty of this research lies in its specific focus on bridging this gap. This study systematically evaluates the impact of LDPE waste-modified asphalt prepared by the wet method on the fundamental characteristics of the AC-BC layer. This area has been largely unexplored. The question is how this modification affects the Marshall parameters, which are key indicators of the mixture's strength and durability. By analyzing parameters such as Stability, Flow, Void in Mix (VIM), Void in Mineral Aggregate (VMA), and Void Filled with Asphalt (VFA), this study will provide valid empirical data on the feasibility and structural potential of LDPE in binder layers . Therefore, the main objective of this study is to quantitatively analyze the effect of variations in the concentration of LDPE plastic waste processed using the wet method on the characteristics and performance of the Marshall mix of Asphalt Concrete-Binder Course (AC-BC)(Genet et al., 2021). The benefits of this research will fill a significant knowledge gap by presenting valid empirical data on the performance of Asphalt Concrete-Binder Course (AC-BC) mixtures modified using LDPE waste through the wet method. Quantitative data on Marshall parameters (Stability, Flow, VIM, VMA, VFA) in this structural layer will form a comprehensive new reference basis for future road pavement material research, particularly in the development of Polymer Modified Bitumen (PMB) from recycled materials.

METHOD

This research was conducted using experimental methods at the Civil Engineering Laboratory of Sriwijaya State Polytechnic. The main objective of this research was to evaluate the effect of adding LDPE plastic waste on the performance of Marshall asphalt mixtures. The research procedure was divided into several main stages, namely:

1. Preparation and testing of materials. The materials used were local aggregates, cement filler, and Low-Density Polyethylene (LDPE) plastic waste from shopping bags. The plastic waste was obtained from the surrounding area and then shredded. This stage, preparation and testing of materials, involved testing aggregate materials, including sieve analysis, specific gravity and water absorption, moisture and mud content, and coarse aggregate wear using a Los Angeles abrasion machine. This was followed by asphalt testing, including asphalt specific gravity, penetration, ductility, and softening point(Wantoro et al., 2013)
2. Asphalt mixture design is the stage of designing the asphalt mixture to determine the required material composition, based on the mixture design through combined aggregate gradation
3. Mixture design with LDPE plastic waste with predetermined LDPE concentration variations of (5%, 6%, 7%) to be added to several mixtures with asphalt content variations around the Optimum Asphalt Content (OAC) of the control mixture(Genet et al., 2021)
4. Marshall testing will be conducted for each LDPE-modified mixture. The parameters tested include Marshall Stability, Flow, Voids in Mix (VIM), Voids in Mineral Aggregate (VMA), and Voids Filled with Asphalt (VFA)(Susilowati et al., 2021) .
5. Determination of Modified KAO, based on Marshall criteria and desired performance (especially for AC-BC), KAO will be determined for each LDPE concentration(Zhang et al., 2024)

The method of mixing plastic waste into the mixture uses the wet mix method, which is the process of making an asphalt mixture by mixing aggregates (crushed stone, sand, filler) with heated asphalt (bitumen), emulsified asphalt (asphalt dispersed in water), or cutback asphalt. Unlike dry mixing, which involves only solid materials, this wet method relies on asphalt as a liquid binder to coat and bind aggregate particles. The research was conducted using local materials, namely fine aggregate (sand), coarse aggregate, medium aggregate, filler in the form of cement, and Pertamina PEN 60/70 asphalt. It referred to the 2018 Bina Marga specifications, and the aggregate material testing referred to the SNI standard (Rahmadona et al., 2024).

The research process began with the preparation of materials and tools, followed by testing of aggregates (fine, medium, and coarse), including sieve analysis, specific gravity and absorption, moisture content, and mud content, and coarse aggregate wear testing using a Los Angeles machine. In addition, tests were also carried out on asphalt, namely, asphalt specific gravity, ductility, penetration, and softening point tests. If the test results met the specified specifications, the asphalt mixture design continued; if they did not, the tests were repeated. Next, after designing the asphalt mixture, make a standard asphalt mixture with asphalt contents of 4.5%, 5%, 5.5%, 6%, and 6.5%. After that, an asphalt mixture is made with LDPE plastic waste at 5%, 6%, and 7%, with three samples for each. The plastic waste here ranges from 4.5% to 6.5% in asphalt. Then, the test objects were subjected to Marshall testing, through which the stability, flow, Marshall question, Void in Mix (VIM), Void Filled with Asphalt (VFA), and Void in Mineral Aggregates (VMA) values were obtained. Next, the test results were discussed in more depth, and conclusions were drawn.

RESULTS AND DISCUSSION

The research began with physical testing of aggregate and asphalt materials to ensure they met the specifications. Physical testing for aggregates included sieve analysis(Yaqin, 2012), specific gravity and absorption (Nasional, 1990)

(Badan Standar Nasional Indonesia, 1970), moisture and mud content (SNI 03-1971-1990, n.d.), and coarse aggregate abrasion using a Los Angeles machine.

Table 1. Recapitulation of the Results of Physical Testing of Aggregates and Asphalt

No	Type of Testing	Method	Result				Specification	
			Coarse Aggregate	Medium Aggregate	Fine Aggregate	Asphalt	Min	Max
1	Sieve Analysis	SNI ASTM C136:2012	8.20	6.41	3.79		-	-
2	Bulk	SNI 1969:2008	2.46	2.43	2.31		2.4	2.7
3	SSD	SNI 1969:2008	2.51	2.46	2.40		2.4	2.7
4	Apparent	SNI 1969:2008	2.60	2.52	2.55		2.4	2.7
5	Absorption	SNI 1969:2008	2.13	1.51	4.23		0	3
6	Abrasion with Los Angeles Machine	SNI 2417:2008	14.84	-	-		0	30%
7	Water content	SNI 03-1971-1990	2.07	0.61	2.92		0	3
8	Mud content	SNI 03-1971-1990	0.26	0.43	1.09		0%	5% (Coarse Aggregate) 1% (Fine Aggregate)
9	Specific gravity	SNI 06-2441-1991	-	-	-	1.0	1 g/ml	-
10	Ductility, 25°C	SNI 06-2432-1991	-	-	-	105	100 cm	-
11	Penetration (25°C, 5 sec)	SNI 06-2456-1992	-	-	-	68	60	70
12	Softening point, °C	SNI 06-2434-1991	-	-	-	51.5	48°	58°

Source: Research Result (2025)

Physical testing of aggregate materials has been conducted, namely sieve analysis testing to obtain the Fineness Modulus (FM) value. The results show that the specific gravity and dominant absorption are within the specified range of 2.4-2.7. In contrast, the moisture and mud contents of coarse aggregates meet the specifications, with a maximum mud content of 5% and a maximum acceptable aggregate silt content of 1%. The results of the coarse aggregate wear test using the Los Angeles machine met the maximum crushing specification of 30%. In addition, physical tests for asphalt include specific gravity, ductility, penetration, and softening point. According to the test results, the material meets the 2018 Bina Marga standard specifications, allowing it to be used in AC-BC mixtures. The next step is to design the aggregate proportions to determine the percentage of each aggregate fraction as the asphalt estimate value (Pb). Asphalt mix material consists of sand, coarse and medium aggregate, and cement used as filler.

Table 2. Combined Aggregate Grading AC-BC

Sieve Size	Fine Aggregate	Coarse Aggregate	Medium Aggregate	Filler	Combined Aggregate Gradation	% Passed Specification		
No	%	%	%	%		Minimum Limit		Maximum Limit
1 1/2"	100.00	100.00	100.00	100	100	100	-	100
3/4"	100.00	100.00	83.64	100	94.11	90	-	100
1/2"	100.00	81.18	65.07	100	82.72	75	-	90
3/8"	100.00	72.42	30.58	100	68.11	66	-	82
4	98.76	53.39	0.00	100	51.89	46	-	64
8	97.26	35.75	0.00	100	46.92	30	-	49
16	87.99	5.39	0.00	100	35.90	18	-	38
30	18.50	5.35	0.00	100	10.18	12	-	28
50	11.74	2.83	0.00	100	7.05	7	-	20
100	5.82	2.74	0.00	100	4.84	5	-	13
200	0.00	0.00	0.00	100	2.00	4	-	8

Source: Research Result (2025)

In this study, the AC-BC mixture used the 2018 Bina Marga specification standard. The planned gradation of the AC-BC mixture is presented in Table 1 and illustrated in a graph showing the relationship between sieve size and the percentage of aggregate passing through the sieve. Next, the aggregate composition was determined based on the combined aggregate gradation that met the specifications for AC-BC mixtures in accordance with the 2018 Bina Marga specifications. Based on the data analysis, the percentages were sand 37%, medium aggregate 25%, coarse aggregate 36%, and cement filler 2%.

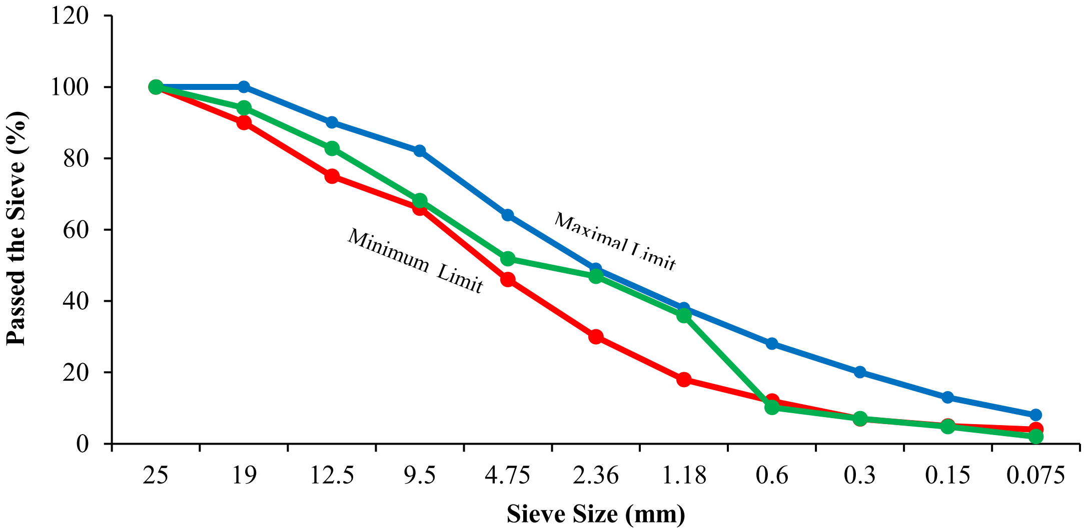

Figure 2. Combined Aggregate Gradation
Source: Research Result 2025)

After determining the combined aggregate gradation and aggregate percentage composition, the next step is to plan the estimated asphalt content (Pb) or average asphalt content. This plan is intended to facilitate the determination of the Optimum Asphalt Content (OAC). Based on the calculation results, a Pb value of 5.5% was obtained. Next, to determine the OAC value in a standard AC-BC mixture without a plastic admixture, two variations of asphalt content were prepared: one below and one above the Pb value, with an interval of 0.5%. Thus, the variations in asphalt content to determine the OAC value in the AC-BC mixture were 4.5%, 5%, 5.5%, 6%, and 6.5%. For each asphalt content variation, three test specimens will be tested using the Marshall method. From the Marshall test results, parameters such as stability, melting, MQ, Void in Mix (VIM), Void Filled with Asphalt (VFA), and Void Mineral Aggregates (VMA) were obtained (Marelo & Nataadmadja, 2023). The Marshall test results for the AC-WC mixture to determine the OAC value are presented in Table 3 and displayed in a bar chart, as shown in Figure 3 below.

Table 3. Marshall Test Results

Test Item Number	Item Number Code	Asphalt Content (%)	VIM	VMA	VFA	Stability	Flow	Marshall Question (MQ)
			%	%	%	Kg	mm	
1	1A	4.5	4.98	14.25	64.73	1355.00	3.73	362.83
2	2A	5	4.75	14.12	66.80	1434.00	4.77	300.94
3	3A	5.5	2.89	16.44	82.51	1687.33	3.73	452.85
4	4A	6	4.24	15.69	73.10	1614.00	3.54	455.50
5	5A	6.5	6.89	18.94	64.39	1213.67	3.63	334.47

Source: Processed Data (2025)

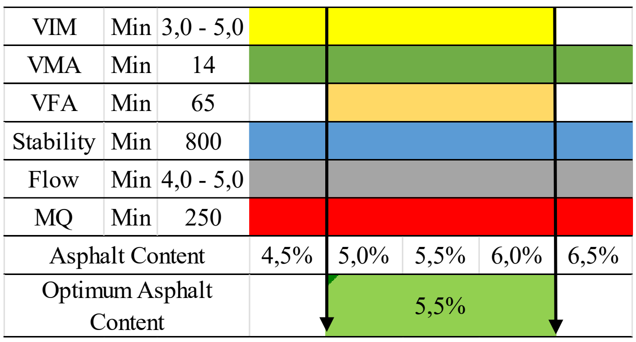

Figure 3. Diagram for Determining the Optimum Asphalt Content
Source: Processed Data (2025)

Based on the Marshall test results, the asphalt content that meets the requirements of the 2018 Road Construction Specifications is 5% to 6%, with an optimum asphalt content of 5.5%. The next step was to make test specimens with varying amounts of LDPE plastic waste added as a partial substitute for asphalt, at 5%, 6%, and 7%. The initial asphalt content was set at around the OAC of a standard AC-BC mixture, so that the asphalt content with plastic waste was set at 5%, 5.5%, 6%, and 6.5%. There were three samples per variation, for a total of 27. The next step was to make test specimens by adding LDPE waste using the wet-mix method, in which LDPE waste was mixed with heated asphalt.

(a) Process Of Mixing Liquid Asphalt With LPDE Plastic (b) Asphalt Mixing Process With Aggregate

Figure 4. Wet Mixing Process

Source : Research Documentation (2025)

Next, Marshall testing was conducted to obtain parameter values, including stability, flow, MQ, VIM, VMA, and VFA values. A summary of the Marshall test results for Laston (AC-BC) mixtures with varying LDPE content is shown in Table 4 below.

Table 4. Marshall Test Results with Plastic Waste Variation

No	Test Item Number	Asphalt Content	Plastic Content	Amount of Void			Stability	Flow	Marshall Question
		%	%	VIM	VMA	VFA	Kg	mm	(MQ)
1	1A	5.00	5.0	4.05	12.68	70.32	1388.33	3.99	347.72
2	1B	5.00	6.0	6.31	15.54	59.43	1896.00	4.51	420.27
3	1C	5.00	7.0	5.45	15.56	67.35	2402.00	3.52	682.90
4	2A	5.50	5.0	2.67	15.85	83.87	1,451.67	3.61	401.72
5	2B	5.50	6.0	2.20	16.24	86.49	2119.67	5.24	404.21
6	2C	5.50	7.0	1.84	16.72	89.09	2194.00	3.92	559.60
7	3A	6.00	5.0	5.30	15.82	66.58	1210.00	3.84	314.89
8	3B	6.00	6.0	5.62	16.90	66.79	1,579.00	3.13	503.78
9	3C	6.00	7.0	5.62	17.68	68.21	2,271.00	3.72	609.88
10	4A	6.50	5.0	5.18	16.31	68.39	1520.67	4.23	359.69
11	4B	6.50	6.0	4.93	16.85	70.85	1656.00	3.60	460.47
12	4C	6.50	7.0	4.97	17.69	71.99	1887.67	3.63	520.02

Source: Processed Data (2025)

The use of LDPE plastic waste as a substitute for asphalt content on the characteristics of AC-BC mixtures will be discussed for each Marshall parameter, including stability, flow, MQ, VIM, VFA, and VMA, as shown in Figures 5 to 10.

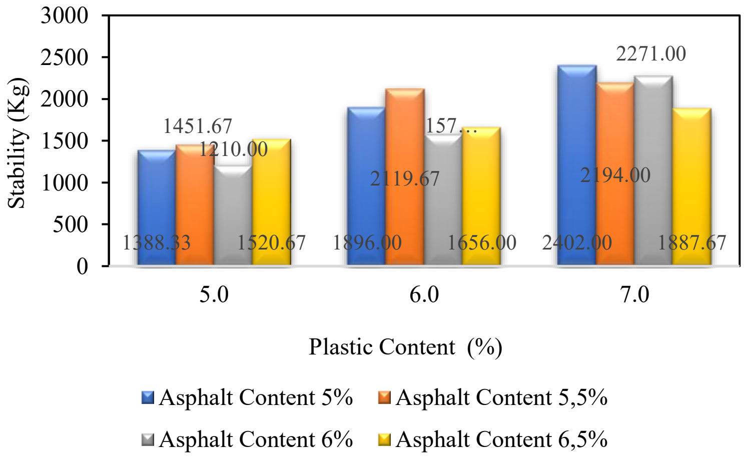

Figure 5. The Relationship Between Stability and Plastic Content

Source: Marshall Test Result (2025)

The test results were then analyzed in relation to the stability values for each asphalt content and for plastic content with variations of 5%, 6%, and 7% as substitutes for asphalt content. Based on the diagram in Figure 5 below, The highest stability value, 2402 kilograms, was identified in the 7% plastic waste variation with 5% asphalt content. The 7% plastic waste variation had the highest average stability among the other variations. This was due to plastic's ability to fill the voids between aggregate particles, making them more compact. All variations of LDPE plastic addition increased the stability value and met the requirements for the laston (AC-BC) mixture, as specified in the 2018 Bina Marga specification.

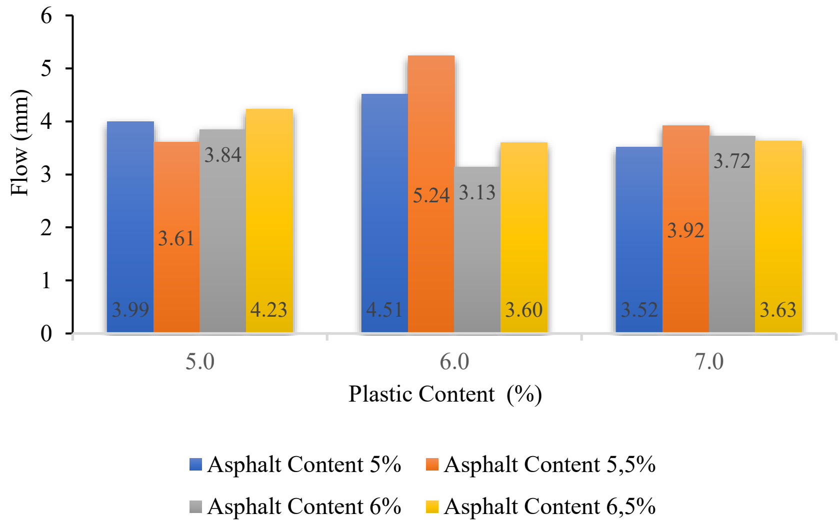

Figure 6. The Relationship Between Flow and Plastic Content
Source: Marshall Test Result (2025)

Adding LDPE plastic waste to the AC-BC asphalt mixture can affect the softening point. By replacing 5%-7 % of the asphalt content with plastic waste, the softening point obtained is in accordance with the 2018 Bina Marga specifications for the AC-BC asphalt mixture, which specifies a softening point range of 4-5. This indicates that varying the plastic waste content can affect the melting point value. Therefore, this variation can be used as a substitute for asphalt content.

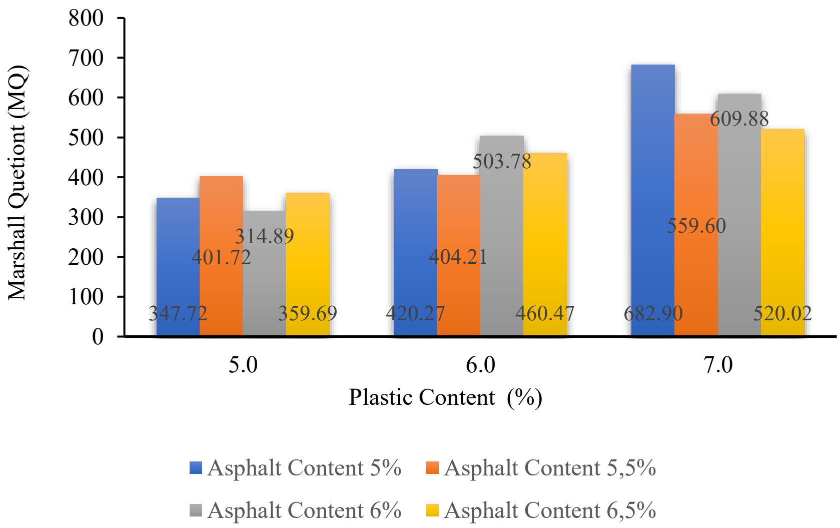

Figure 7. The Relationship Between MQ and Plastic Content
Source: Marshall Test Result (2025)

As the LDPE plastic waste content in the AC-BC mixture increases, the Marshall Quetiont value also increases. Based on the test results, the MQ value increases significantly at a plastic content of 7% for each asphalt content (5%, 5.5%, 6%, and 6.5%). Meanwhile, at a plastic content of 5%, the increase in the MQ value is not very significant.

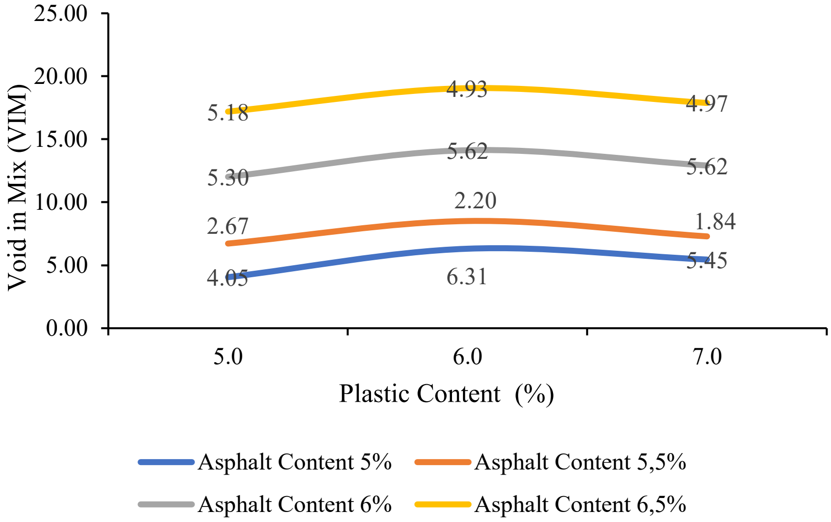

Figure 8. The Relationship Between VIM and Plastic Content
Source: Processed Data (2025)

Based on testing and data processing, the test results show a relationship between plastic content and VIM value. At plastic contents of 6% and 7%, there is a decrease in VIM value, which tends not to meet the specification for VIM values between 3-5, while at a plastic content of 5%, the VIM value tends to increase. The addition of 5% LDPE plastic to the AC-BC mixture was able to increase the VIM value, as shown in Figure 8. From these test results, it can be concluded that the addition of 5% LDPE plastic to the AC-BC laston mixture was able to fill the air voids in the mixture.

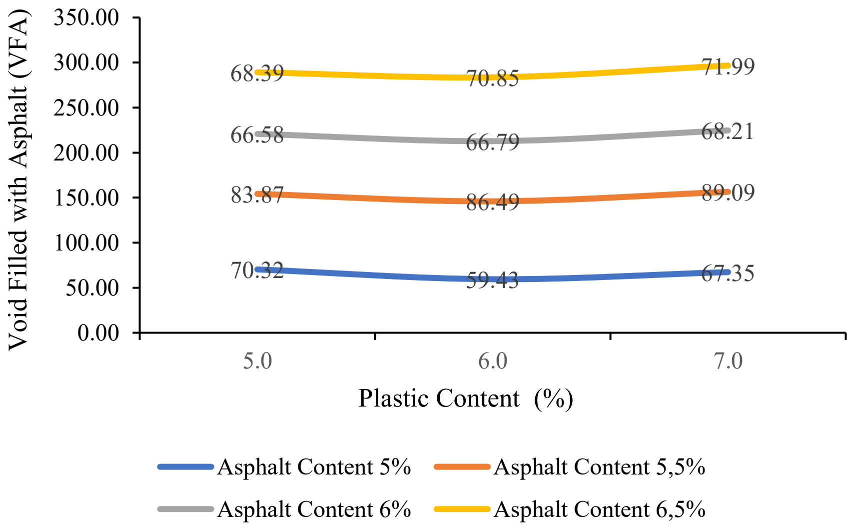

Figure 9. The Relationship Between VFA and Plastic Content
Source: Processed Data (2025)

The graph above shows that the VFA value in the AC-BC mixture using plastic increases when the plastic content is added at a rate of 7%. The lowest VFA value was obtained at a plastic content of 5%, and the highest VFA value was 89.09. This is because the addition of plastic content in the asphalt causes the cavities in the VFA to become increasingly filled, resulting in an increase in the cavities filled with asphalt mixed with plastic.

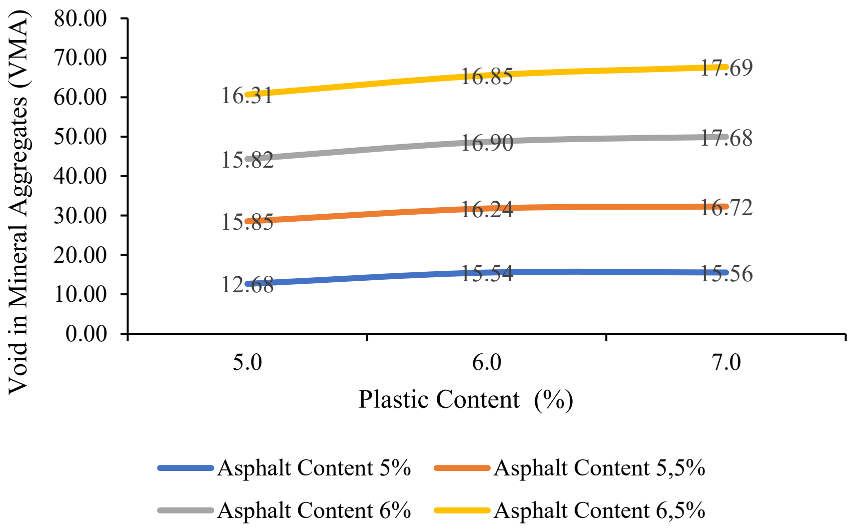

Figure 10. The Relationship Between VMA and Plastic Content
Source: Processed Data (2025)

The graph above shows that the VMA value in the AC-BC mixture using plastic increased when the addition started from 5% to 7%. The highest VMA value was obtained at a plastic content of 7% with a VMA value of 17.69%, and the lowest was at a plastic content of 5% with a VMA value of 12.68%. The addition of plastic to the asphalt mixture affects the VMA value. Well-graded or densely graded aggregates result in small voids between aggregate particles (VMA). This is because the plastic layer has coated the aggregates and closed most of the voids between the particles.

Plastic Content			5,0%			
VIM	Min	3,0 - 5,0				
VMA	Min	14				
VFA	Min	65				
Stability	Min	800				
Flow	Min	4,0 - 5,0				
MQ	Min	250				
Asphalt Content			5,0%	5,5%	6,0%	6,5%
Optimum Asphalt Content					6,0%	

Plastic Content			6,0%			
VIM	Min	3,0 - 5,0				
VMA	Min	14				
VFA	Min	65				
Stabilitas	Min	800				
Flow	Min	4,0 - 5,0				
MQ	Min	250				
Asphalt Content			5,0%	5,5%	6,0%	6,5%
Optimum Asphalt Content					6,0%	

Plastic Content			7,0%			
VIM	Min	3,0 - 5,0				
VMA	Min	14				
VFA	Min	65				
Stabilitas	Min	800				
Flow	Min	4,0 - 5,0				
MQ	Min	250				
Asphalt Content			5,0%	5,5%	6,0%	6,5%
Optimum Asphalt Content					6,3%	

Figure 11. Optimum Asphalt Content Laston AC-BC with Plastic Waste
Source: Processed Data (2025)

Based on the test results and data analysis, the AC-BC mixture using LDPE plastic waste dominantly meets the specifications for each asphalt content used. Thus, the optimum asphalt content for AC-BC with 5% plastic content is 6%, 6% plastic content with KAO value of 6%, and 7% plastic content with KAO value of 6.3%.

CONCLUSION

Based on test results and data processing, it can be concluded that the addition of LDPE to the AC-BC mixture affects Marshall characteristics, both mechanically and volumetrically. Based on the results of the standard Marshall test, the optimum asphalt content was 6% for each plastic content. A mechanical perspective was adopted for the review of Marshall parameters. The addition of LDPE plastic to the AC-BC laston mixture was found to result in increased stability, flow, and Marshall Quotient (MQ). The highest stability value was recorded at an addition rate of 7% with a value of 2402 kg, a flow value of 3.52 mm, and an MQ value of 682.9 kg/mm. In terms of volumetric properties, the addition of LDPE to the AC-BC mixture can increase VIM, VFA, and VMA. Thus, the results of this study provide an overview that the use of LDPE plastic in the AC-BC mixture needs to be considered, as it can affect the Marshall characteristics in terms of both mechanical and volumetric properties.

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