Comparison of Characteristics of Porous Asphalt with HDPE Plastic and PET Plastic as Asphalt Modifiers

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Abstract: This study aims to compare the characteristics of porous asphalt mixtures modified with polyethylene terephthalate (PET) and high-density polyethylene (HDPE) derived from recycled plastic bottles. The porous asphalt mixtures were prepared by partially substituting mineral fillers with PET and HDPE materials. Laboratory tests were conducted to evaluate the physical and mechanical properties, including stability, permeability, density, and void content. The results indicate that the addition of HDPE improves the stability of the porous asphalt mixture more significantly than PET, whereas porous asphalt incorporating PET demonstrated superior permeability properties. These findings suggest the potential of both PET and HDPE as sustainable filler materials in porous asphalt, contributing to the advancement of environmentally friendly pavement engineering.

Keywords: Porous Asphalt Mixture, High-Density Polyethylene (HDPE), Polyethylene Terephthalate (PET).

1. INTRODUCTION

In recent years, the demand for sustainable infrastructure has become increasingly urgent, prompting researchers and practitioners in civil engineering to seek innovative materials that can enhance the performance of mixtures while minimizing environmental impact. One promising approach is the use of recycled materials, such as High-Density Polyethylene (HDPE) and Polyethylene Terephthalate (PET), incorporated into porous asphalt mixtures. HDPE and PET, types of plastics predominantly sourced from bottles and bottle caps, offer opportunities to reduce plastic waste while improving the mechanical properties of porous asphalt mixtures.

According to the World Atlas, cited from Harian Wartakota (2018), Indonesia ranks as the fourth largest consumer of plastic bottles globally, with a reported usage of approximately 4.82 billion bottles per year. Plastics require 450 to 1000 years to decompose, according to the Health Crisis Center of the Indonesian Ministry of Health.

Meanwhile, asphalt is a derivative product of petroleum or obtained naturally. Asphalt derived from petroleum or natural sources is a non-renewable material whose quantity continues to decrease with use in road construction. Both asphalt and plastics possess thermoplastic properties, i.e., the ability to soften when heated and harden again upon cooling, albeit with different melting points. Therefore, plastics such as HDPE and PET hold potential as modifiers in asphalt materials for porous asphalt mixtures.

One of the principal adversaries of asphalt pavement is water. Samarinda city, being highly prone to flooding, experiences this due to its low-lying topography compared to the Mahakam river's water level during the rainy season. The design of porous asphalt mixtures with high stability and permeability is critically needed in urban areas like Samarinda city.

This study aims to investigate the effect of utilizing HDPE and PET plastics as modifiers in porous asphalt mixtures on their physical and mechanical characteristics. Through a series of laboratory tests, this research evaluates how the addition of these two plastic types influences the Marshall characteristics and permeability of the asphalt mixture. The empirical data generated is expected to provide valuable insights for future applications in road construction.

2. LITERATURE REVIEW

2.1 Porous Asphalt Mixture

Porous asphalt mixture is a combination of coarse aggregate, fine aggregate, and modified asphalt binder. This mixture is designed with an open gradation that features interconnected voids, significantly enhancing the surface drainage capability of roadways. The proportion of coarse aggregate in porous asphalt typically ranges from 70% to 85%. Increasing the coarse aggregate ratio contributes to a reduction in stability compared to conventional pavement structures (Djumari, 2009).

In the production of porous asphalt mixtures, it is crucial to ensure the composition is properly formulated to guarantee optimal performance, so that the mixture possesses strength and durability against weather conditions and traffic loads. The composition of porous asphalt consists of:

1. Asphalt 60/70
   Asphalt penetration grade 60/70 is commonly used in road construction and paving because it has characteristics suitable for most road construction applications. This asphalt is sufficiently soft at operational road temperatures to adhere well to aggregates, while being hard enough at normal temperatures to resist traffic loads.
2. Aggregate Gradation
   Gradation refers to the distribution of aggregate particle sizes within a specified range and the proportion of each particle size must be precise (I Gusti, 2015). Aggregate gradation affects the size of voids within the mixture and determines workability and stability. Gradation is determined by sieve analysis, where aggregate samples pass through a set of sieves. Gradation values are expressed as the percentage retained or passing, calculated from the aggregate weight (Juharni, 2015).

Currently, the design of porous asphalt mixtures is not regulated under the Indonesian National Standard (SNI); therefore, research refers to the Australian Asphalt Pavement Association (AAPA) 2004 standards. The design aims to improve surface drainage, reducing hydroplaning risk and enhancing road user safety under wet conditions. The interconnected voids allow efficient water flow, helping maintain surface integrity and contributing to overall pavement durability. However, increased drainage capacity comes with the downside of reduced structural stability of the mixture.

Therefore, a deep understanding of the characteristics and behavior of porous asphalt mixtures is essential to optimize their use in road construction, especially in the context of sustainability and infrastructure safety.

2.2 Characteristics of Porous Asphalt Mixture

The characteristics of porous asphalt mixtures refer to the properties of the asphalt pavement used in the production of the mixture, evaluated through Marshall testing and permeability testing. Key characteristics of porous asphalt include stability, flow, Void in Mix (VIM), Marshall Quotient (MQ), and permeability.

Tabel 1. Kriteria Perencanaan Aspal Porus (AAPA, 2004)

Kriteria Perencanaan	Nilai
Stabilitas (*kg*)	Min. 500
Flow (*mm*)	2 – 6
Void In Mix (*VIM %)*	18 – 25
Marshall Quotient (*kg/mm*)	Max. 400
Permeabilitas (*cm/detik*)	0.1 – 0.5

These design criteria serve as benchmarks for evaluating test results. According to Table 1, the minimum asphalt stability for porous asphalt is 500 kg; if used as a wearing course, a minimum stability of 800 kg is required (General Specifications of Bina Marga, 2018). Elsa (2019) made porous asphalt mixtures with HDPE plastic and found the highest stability value of 870 kg, but the VIM value obtained was only 16.17%, not meeting AAPA (2004) specifications. Syammaun (2020) created porous asphalt mixtures adding coconut shell ash and PET plastic, achieving a stability value of 556 kg and a VIM value meeting the criteria at 22.95%.

2.3 High Density Polyethylene (HDPE)

High Density Polyethylene (HDPE) is a type of thermoplastic polymer consisting of long chains of high-density polyethylene, producing a hard, strong, and durable material. HDPE is widely used in applications requiring resistance to pressure, abrasion, extreme temperatures, and chemicals (Elsa, 2019).

The melting point of HDPE ranges from 200°C to 280°C, allowing the material to be easily shaped when heated to a molten state. HDPE exhibits tensile strength from 3100 to 5500 psi, making it one of the strongest and hardest materials available, with excellent opacity and superior resistance to higher temperatures (Hardiman, 2018). Elsa's 2019 research using HDPE as an additive in porous asphalt identified the optimal HDPE content at 4%. Izzanur (2018) found the optimal HDPE content to be 15% as an additive in porous asphalt mixtures.

HDPE shares thermoplastic properties similar to asphalt; therefore, it is tested as a material modifier for asphalt. If successful, HDPE use could reduce plastic waste in the environment.

2.4 Polyethylene Terephthalate (PET)

PET polymer is a polyester resin characterized by ease of molding when heated, good strength and durability, gas barrier capacity, and thermal and chemical stability (Syammaun, 2020). PET has sufficient tensile and compressive strength to withstand significant loads, which can improve ride comfort and reduce damage risk to vehicles.

In this study, plastic is used as a partial asphalt modifier. Zoorob S.E. (2000) proposed two methods to enhance asphalt mixture performance with plastic: the wet method and the dry method. The wet method involves mixing plastic into hot asphalt and stirring until homogeneous, whereas the dry method involves adding plastic into heated aggregates before adding hot asphalt.

PET melting point varies slightly depending on production and additives, generally ranging from 220°C to 260°C. Researchers like Zukisa (2023) used PET as an asphalt modifier in porous asphalt mixtures, finding the optimal PET content at 1%. In 2020, Syammaun found the highest stability value at 4% PET content.

2.5 Permeability

Permeability testing aims to determine the water flow capability through the porous asphalt surface layer. Water easily enters the pavement and is discharged from the surface. This test is based on the falling head method by Braja M. Das (1995). The permeability formula is stated as:

$$K = 2{,}3\,\frac{aL}{At}\ x\ \left(log\,\frac{h1}{h2}\right) \tag{1}$$

Where:

K = water permeability coefficient (cm/sec)
A = cross-sectional area of the tube (cm^2)
L = thickness of the specimen (cm)
A = cross-sectional area of the specimen (cm^2)
t = time for water to flow from height h1 to h2 (seconds)
h1 = initial water head in the tube (cm)
h2 = final water head in the tube (cm)

(a) Permeability Sample

(b) Permeability Testing Proces

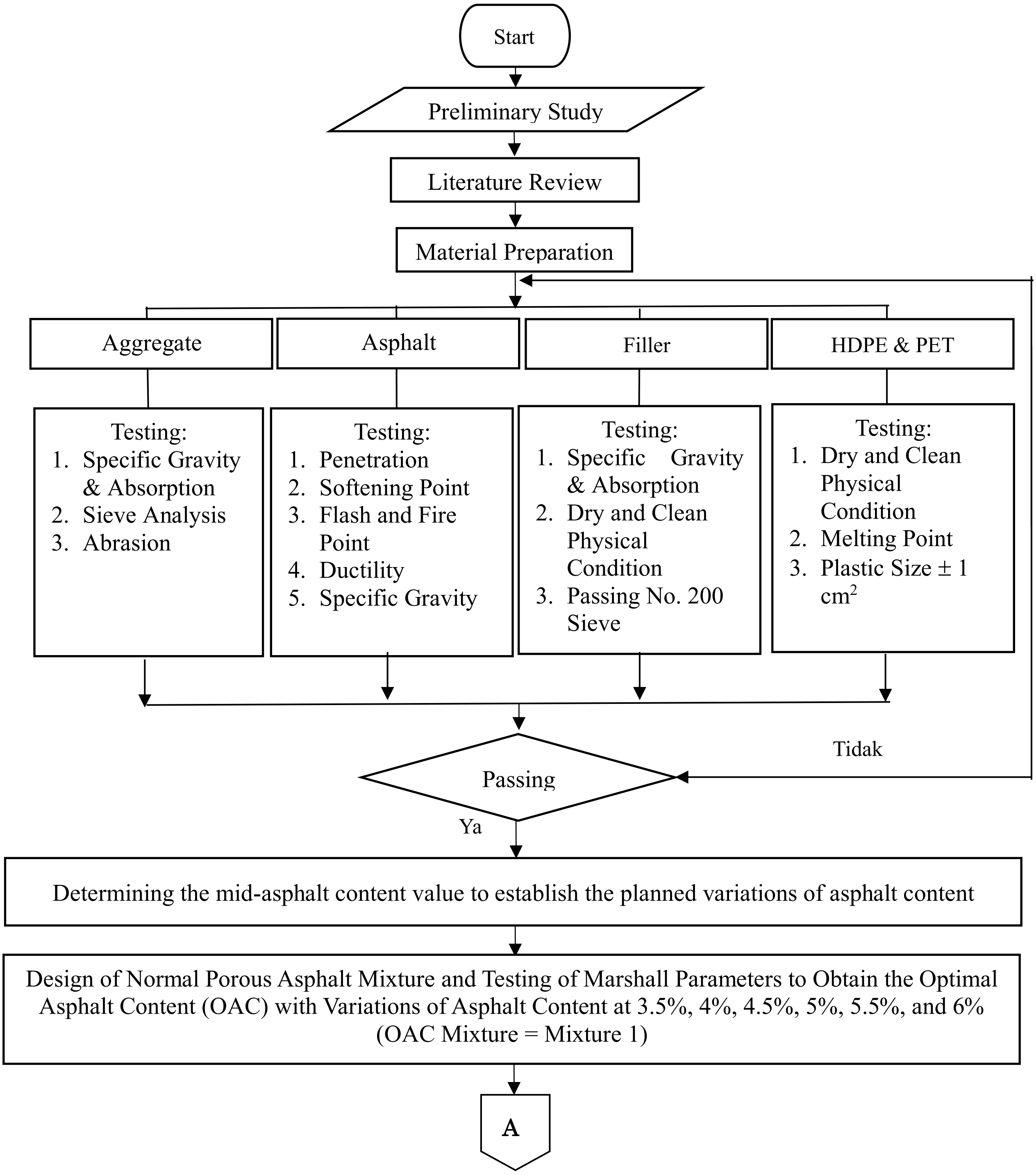
Figure 1. Permeability Testing Proces

The test is conducted by placing a compacted specimen (Figure 1a) into a permeability tube (Figure 1b), designed according to the specimen's cross-sectional area, sealing the sides with plastisin to prevent side seepage, then filling water to heights 8 cm (h2) and 20 cm (h1). Subsequently, the flow rate of water passing through the specimen is measured.

3. METHODOLY

3.1 Flowchart

A flowchart is used to illustrate all the stages of the research activities. The flowchart for this research is presented in Figure 2.



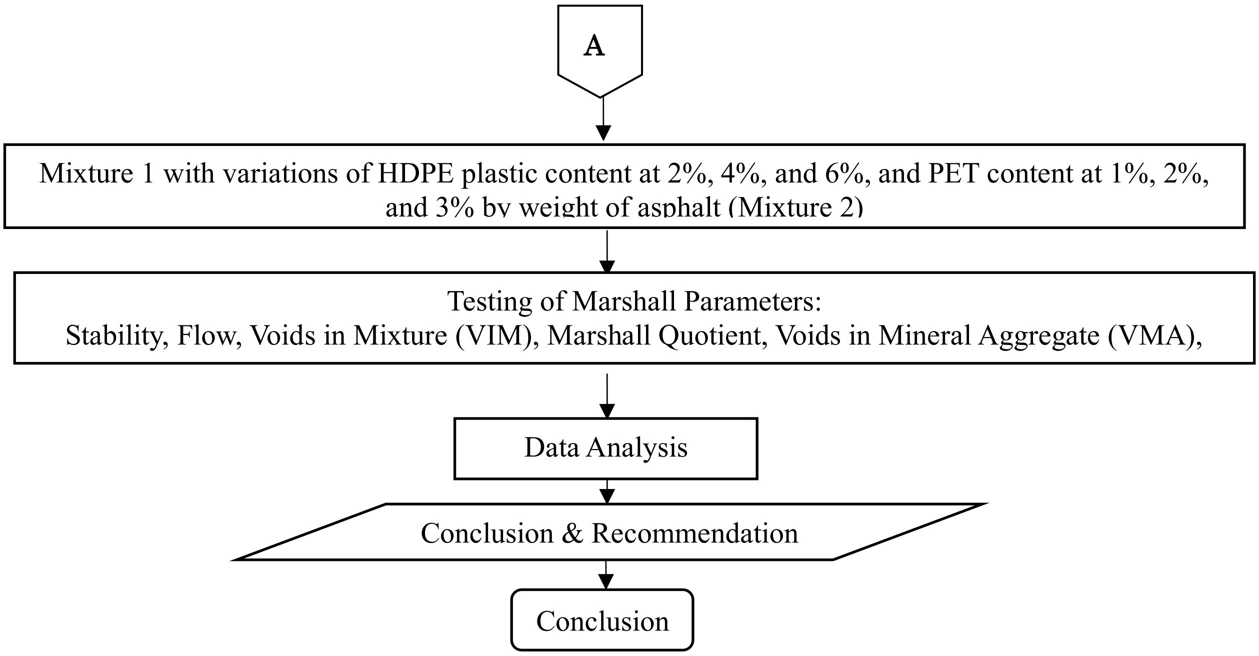


Figure 2. Research Flowchart

3.2 Preparation of Porous Asphalt Mixtures

In this study, prior to the preparation of porous asphalt mixtures, gradation planning and determination of the optimum asphalt content were conducted. The gradation planning aimed to obtain a design that complies with the specification of Open Graded Asphalt (OGA) AAPA 2004. This design was developed through sieve analysis by calculating the percentage weight of aggregates passing each sieve size. Meanwhile, the determination of the optimum asphalt content sought to define the percentage composition of asphalt required to prepare porous asphalt test specimens, following the reference standard from Bina Marga No:001-03/BM/2006, entitled "Determination of Optimum Asphalt Content for Hot Mix Asphalt Mixtures Using Processed Asphaltenes."

After obtaining the gradation plan and the optimum asphalt content, modified asphalt was produced with plastic contents of HDPE at 2%, 4%, and 6%, and PET at 1%, 2%, and 3%. The blending process between the pure asphalt and plastics followed these procedures:

1. Shredding HDPE and PET plastics to sizes around ±0.5 cm.
2. Adding asphalt and the plastic shreds according to the predetermined content into a kiln and heating.
3. Stirring the asphalt-plastic mixture until it becomes homogeneous.
4. Maintaining the mixing temperature to avoid reaching the asphalt flash point during stirring.
5. Pouring the homogeneous mixture into testing molds.

Figure 3. Making modified asphalt HDPE and PET

Next, the preparation of the porous asphalt mixture was carried out. The process began with heating the asphalt to reach an optimal viscosity level, a fundamental stage because the asphalt's viscosity affects its bonding ability with aggregates. Afterward, aggregates were accurately weighed according to their gradation, then combined in plastic bags to ensure homogeneity. The aggregates were not directly mixed but placed first into trays and dried in an oven at 150°C for 30 minutes to one hour. This drying process was vital to remove moisture that could negatively affect the bonding between the asphalt and aggregates and to ensure the aggregate temperature was suitable for mixing.

The following step involved asphalt preparation. The weight of the mixing pan was measured and tare, after which the asphalt was added and weighed according to the percentage variations of asphalt content to be used. This step was crucial since asphalt content significantly influences the final mixture characteristics. Then, the heated aggregates were added into the pan containing the asphalt and thoroughly mixed. During mixing, the temperature of the mixture was monitored using a metal thermometer until approximately 150°C, ensuring proper mixing at optimal working temperature.

With the prepared mixture, specimen molding was next. The mold was placed on a compaction plate and secured with clamps. To prevent sticking and facilitate specimen removal, paper cut to mold diameter was placed at the mold's base. The asphalt mixture was then poured into the mold, leveled with a spatula, and tamped—15 times on the edges and 10 times at the center—to ensure even distribution and removal of large entrapped air voids. Similar paper was placed on top of the mold afterward.

Figure 4. Printing and compaction of test specimens

The peak of this process was compaction. The mixture was compacted by 50 blows using a compaction hammer with a drop height of 45.7 cm, adhering to the porous asphalt mixture specification in AAPA 2004. To ensure uniform compaction, the mold was flipped, and compaction repeated with 50 blows on the specimen's underside at the same height. Throughout the compaction process, it was essential to maintain the hammer's axis perpendicular to the mold base to achieve consistent compaction.

Finally, the mold was removed from the compaction plate and mounted on the specimen extruder or jack. Each specimen was labeled according to the asphalt content used for identification and further analysis. The specimens were then allowed to rest for 24 hours at room temperature, enabling the mixture to harden and reach stability before conducting subsequent tests.

The total number of porous asphalt mixture samples prepared was 48, as shown in Table 2. This study used the ideal gradation based on the OGA 14 specification (AAPA, 2004), illustrated in Figure 5.

Table 2. Testing Specimen Requirements for Porous Asphalt Mixtures

Marshall Testing	
Testing Specimens	Number of Samples
Mixtures with Variations of Asphalt Content at 3.5%, 4%, 4.5%, 5%, 5.5%, and 6% to Determine the OAC	18 Samples
Mixture 1 (OAC 4.6%)	3 Samples
Mixture 2 (Mixture 1 + variations of asphalt substitution with HDPE plastic at contents of 2%, 4%, and 6% & PET plastic at contents of 1%, 2%, and 3%)	18 Samples
Permeability Testing	
Testing Specimens	Number of Samples
Mixture 1	3 Samples
Mixture 2 (Optimal Plastic Content of HDPE at 4% and PET at 2%)	6 Samples
Total Number of Testing Specimens	48 Samples

3.3 Mixture and Material Testing

Aggregate testing was conducted based on the Indonesian National Standard (SNI) as specified in the 2018 General Specifications of Bina Marga Division 6, and the Australian Asphalt Pavement Association (AAPA) 2004 specifications. The aggregate tests included:

1. Sieve analysis of coarse and fine aggregates according to Open Graded Asphalt (AAPA) 2004.
2. Specific gravity and absorption of coarse aggregates based on SNI 03-1969-2008.
3. Specific gravity and absorption of fine aggregates based on SNI 03-1970-2008.
4. Aggregate abrasion or wear by Los Angeles machine according to SNI 03-2417-2008.

Asphalt testing was conducted based on the Indonesian National Standard (SNI) per the 2010 Revision 3 of the Bina Marga General Specifications for hard asphalt. The asphalt was tested with five standard tests as follows:

1. Specific gravity test of asphalt based on SNI 2441-2011.
2. Penetration test based on SNI 2456-2011.
3. Softening point test based on SNI 2434-2011.
4. Flash point and fire point test of asphalt according to SNI 2433-2011.
5. Ductility test of asphalt based on SNI 2432-2011.

Furthermore, the Marshall test was conducted on the porous asphalt mixture to obtain results that meet the parameters in porous asphalt design characteristics. In this study, the

Marshall test was performed according to RSNI M-01-2003 "Hot Mix Asphalt Mixture Testing Method Using the Marshall Apparatus".

4. RESULT

4.1 Testing of Aggregate and Asphalt Materials

The asphalt tested was mixed with HDPE or PET. HDPE and PET materials act as asphalt modifiers, meaning that for every 10 grams of asphalt required, the modified asphalt mixture contains 2% HDPE or 2 grams, and 8 grams of pure asphalt.

Material examination included sieve analysis of aggregates, testing of coarse aggregates, fine aggregates, filler, normal asphalt, melting point tests of asphalt and HDPE & PET plastics, and modified asphalt with HDPE plastic variations of 2%, 4%, and 6% or PET with variations of 1%, 2%, and 3%. The test results are presented in Figure 5, Table 3, Table 4, and Table 5.

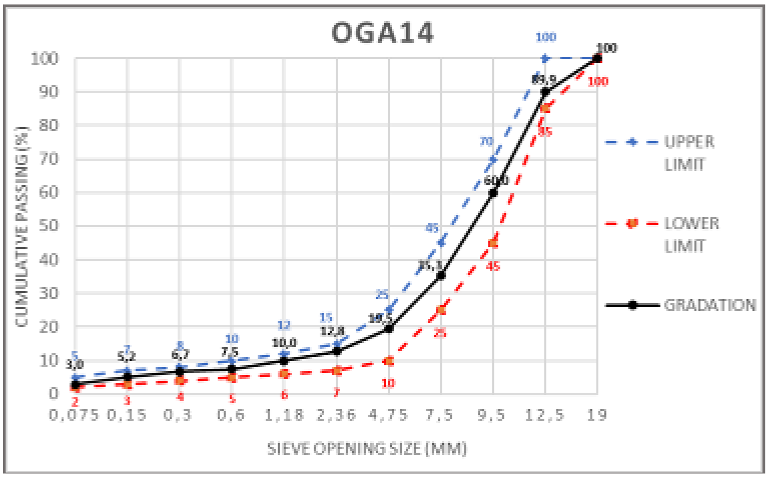


Figure 5. Middle Gradation Graph of Sieve Analysis

Table 3. Results of Aggregate and Filler Material Testing

Test	Results		
	Coarse Aggregate	Fine Aggregate	Stone Ash
SSD Specific Gravity (*gr/cm*^{3})	2,74	2,55	2,30
Bulk Specific Gravity (*gr/cm*^{3})	2,70	2,49	2,23
Apparent Specific gravity (*gr/cm*^{3})	2,81	2,66	2,40
Absorption (*%*)	1,43	2,57	3,09
Aggregate Wear		19.68%	

Table 4. Results of Normal and Modified Asphalt Testing

Test (AAPA, 2004)	Normal Asphalt	Modified Asphalt						Specifications
		HDPE	PET	6%	1%	2%	3%	
		2%	4%	1,000	1,019	1,008	1,005	≥1,0
Specific Gravity (gr/cm3)	1,006	1,012	1,009	64,7	68,8	64	62,4	60

Penetration (mm)	66	67,3	66,7	51	51	50	55	≥48
Softening Point (°C)	49,5	52	50	367	350	356	360	≥232
Flash and Fire Point (°C)	360	361	358	112,5	140	140	127,5	≥100

Table 5. Results of the Melting Point Tests for Asphalt and Plastics

Melting Point Tests	Temperature
Normal Asphalt	60ºC
HDPE Plastic	260ºC
PET Plastic	220ºC

4.2 Optimal Asphalt Content

This test determines the percentage composition of asphalt required in specimen preparation through sieve analysis using the following equation:

$$Pb = 0{,}035\ (\%CA) + 0{,}045\ (\%FA) + 0{,}18\ (\textit{Filler}) + K \quad (2)$$

Where,

Pb	= Optimal asphalt content
CA	= coarse aggregate retained on sieve No. 4
FA	= Fine aggregate passing sieve No. 4 and retained on sieve No. 200
Filler	= filler material passing sieve No. 200
K	= constant with a value from 0.5 to 1.0

In this study, determining the Optimal Asphalt Content (Pb) involves finding the KAO value with asphalt contents of (Pb-1)%, (Pb-0.5)%, Pb%, (Pb+0.5)%, (Pb+1)%, and (Pb+1.5)%.

Table 6. Middle Asphalt Content

Type of Mixture	Gradation (%)			Constant	Pb
	CA	FA	FF		
Porous Asphalt Mixture	80	17	3	0,5	4,5%

The summary of Stability, Flow, VIM, and MQ tests on porous asphalt mixtures at the Optimal Asphalt Content (KAO) is presented in Table 7.

Table 7. Marshall Testing of Optimal Asphalt Content

Marshall Characteristics	Asphalt Content Variations						Specifications (AAPA, 2004)
	3,5%	4%	4,5%	5%	5,5%	6%	
Stability (*kg*)	376	457	677	740	722	697	≥ 500
Flow (*mm*)	3,24	3,9	4,85	5,8	6,5	6,49	2 - 6
VIM (*%*)	24,99	24,35	23,49	22,75	21,94	21,11	18 - 25
MQ (*kg/mm*)	116,08	117,18	139,67	127,50	111,08	107,43	≤ 400

To obtain the Optimal Asphalt Content (KAO), graphs displaying the upper and lower limits of each Marshall parameter tested on modified porous asphalt mixtures were created.

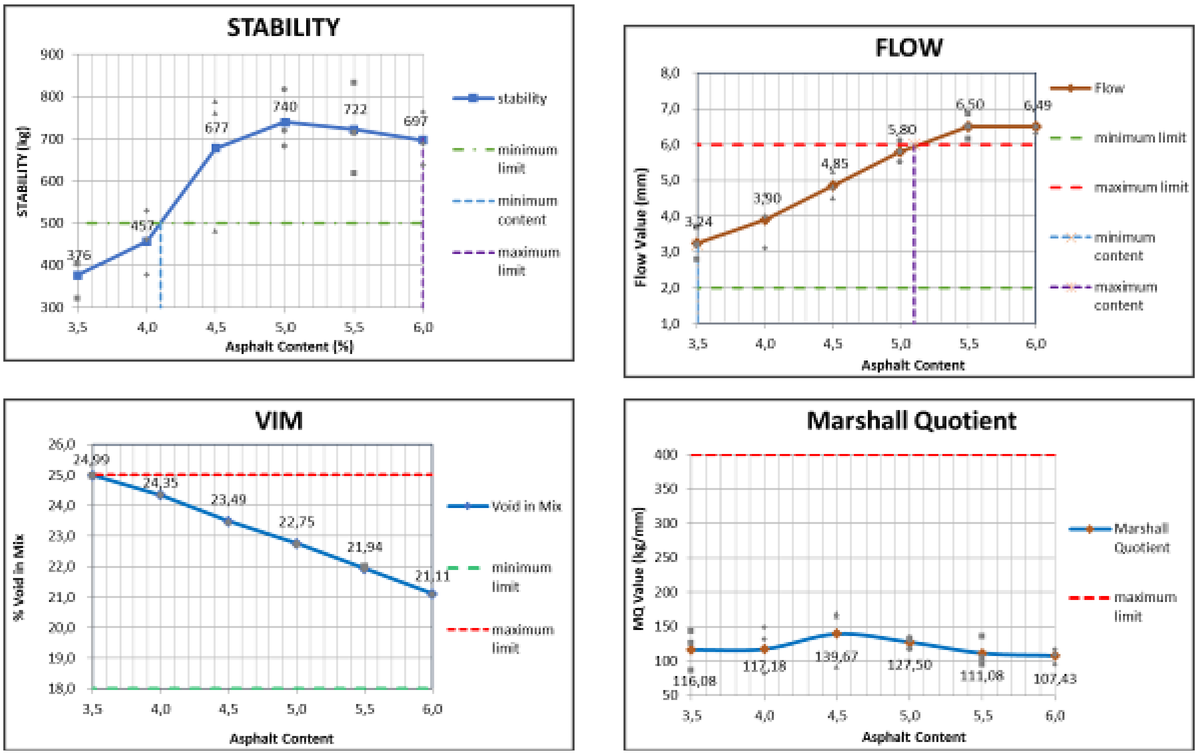


Figure 6. Marshall Characteristics Graph of Optimal Asphalt Content

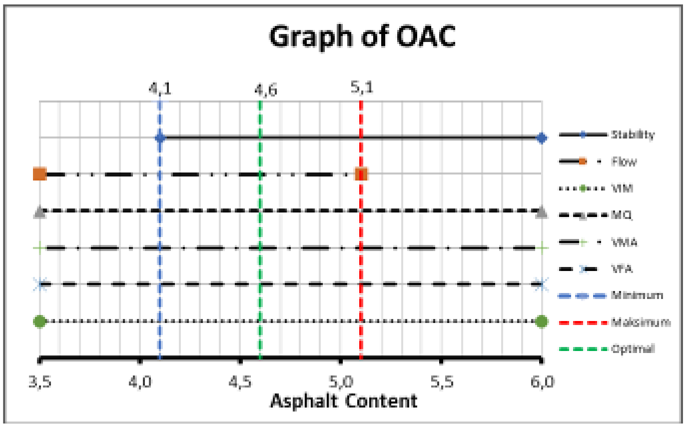


Figure 7. Graph of Optimal Asphalt Content

The Optimum Asphalt Content was found to be 4.6%, as shown in Figure 7. Porous asphalt mixtures using this KAO value are referred to as Mixture 1**.**

4.3 Marshall Characteristics of Modified Asphalt Mixtures

Next, the asphalt content in Mixture 1 was modified by using HDPE or PET as asphalt modifiers. HDPE variations as an asphalt modifier were 2%, 4%, and 6%, while variations for PET were 1%, 2%, and 3%. This modified asphalt mixture is called Mixture 2. The Marshall test results for Mixture 1 and Mixture 2 are shown in Table 8 and Table 9.

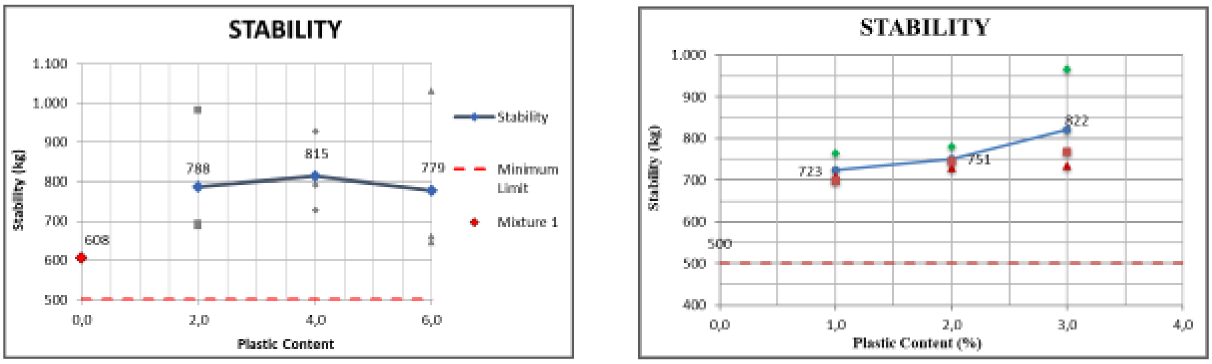
Table 8. Marshall Characteristics of Mixture 1

Marshall Characteristics	Optimal Asphalt Content (4,6%)			Specifications (AASHTO, 2004)
	Sample 1	Sample 2	Sample 3	
Stability (*kg*)	549,1	758,9	513	≥ 500
	Average: 608			
Flow (*mm*)	5,6	5,15	5	2 – 6
	Average: 5,25			
VIM (*%*)	22,12	21,93	22,83	18 – 25
	Average: 22,29			
MQ (*kg/mm*)	98,06	147,36	102,6	≤ 400
	Average: 116,01			

The Marshall characteristic values in Table 9 represent the average of 3 samples. In Figures 6 and 7, each point represents a single sample's value, while the line represents the average value.

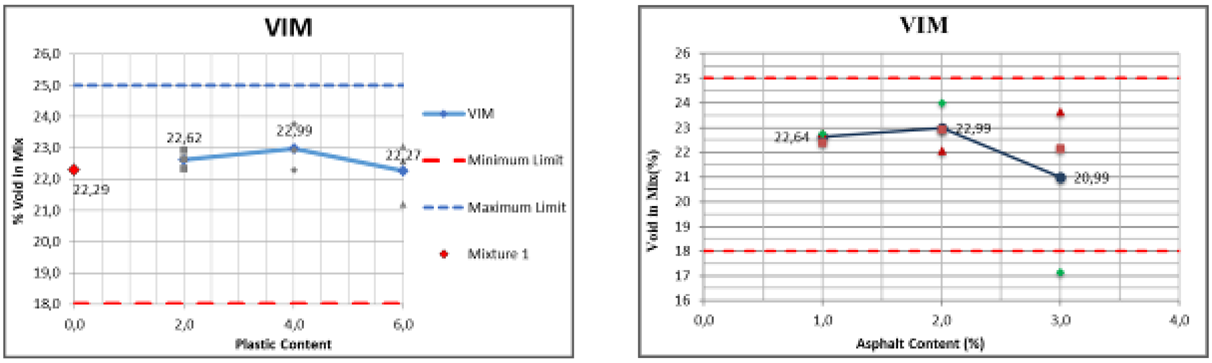
Table 9. Marshall Characteristics of Mixture 1

Marshall Characteristics	HDPE			PET			Specifications (AAPA, 2004)
	2%	4%	6%	1%	2%	3%	
Stability (kg)	788	815	779	723	751	822	≥ 500
Flow (mm)	5,67	5,44	5,15	3,75	5,07	5,78	2 - 6
VIM (%)	22,62	22,99	22,27	22,64	22,99	20,99	18 - 25
MQ (kg/mm)	138,98	149,82	151,26	224,32	148,64	142,42	≤ 400



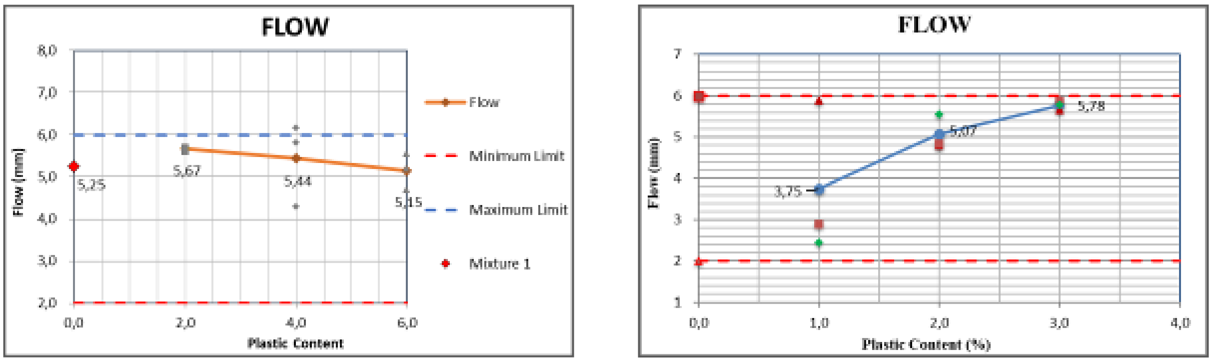
a. Stability graph for HDPE b. Stability graph for PET Mixture 2

Figure 8. Stability Graph for HDPE and PET Mixture 2



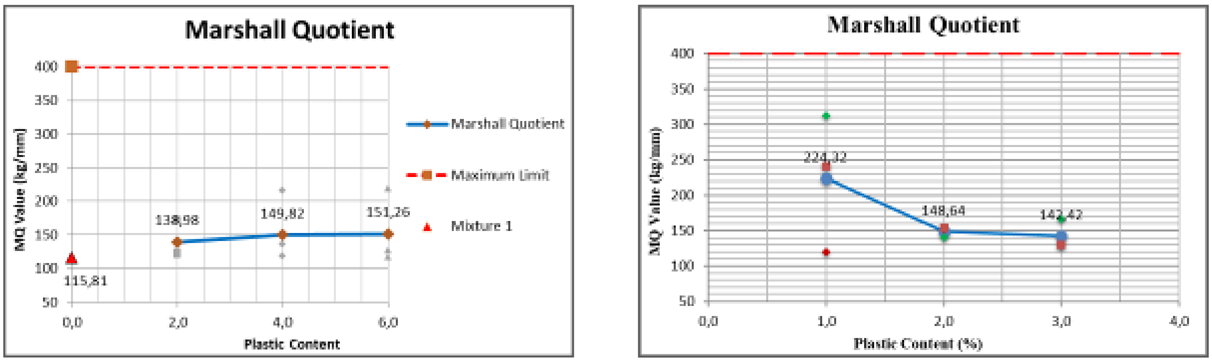
a. VIM graph for HDPE Mixture 2 b. VIM graph for PET Mixture 2

Figure 9. VIM (Void in Mix) Graph for HDPE and PET Mixture 2



a. Flow graph for HDPE Mixture 2 b. Flow graph for PET Mixture 2

Figure 10. Flow Graph for HDPE and PET Mixture 2



a. MQ graph for HDPE Mixture 2 b. MQ graph for PET Mixture 2

Figure 11. MQ Graph for HDPE and PET Mixture 2

Figures 8 to 11 demonstrate that the Marshall characteristics of porous asphalt mixtures modified with HDPE outperform those modified with PET. The average Stability value for porous asphalt with HDPE is 794 kg, while that for porous asphalt with PET is 765.3 kg.

Mixture 1, which is the porous asphalt mixture with an optimal asphalt content of 4.6%, was tested for permeability. This test result serves as a comparison to the permeability values of porous asphalt mixtures modified with 4% HDPE and 2% PET. The permeability test results are shown in Table 10.

Table 10. Permeability Testing

Parameter	Mixture 1	Mixture 2		Specifications (AAPA, 2004)
		HDPE 4%	PET 2%	
Permeability	0,330	0,294	0,447	0.1 - 0.5 (cm/s)

The porous asphalt mixture without HDPE or PET (Mixture 1), as shown in Table 9, had a permeability value of 0.330 cm/second, which is better than the permeability of the porous asphalt mixture modified with 4% HDPE.

The permeability values of three samples from porous asphalt mixtures with HDPE and PET are shown in Figure 12. The red points indicate the average values from the three samples of porous asphalt mixtures with HDPE and PET, respectively.

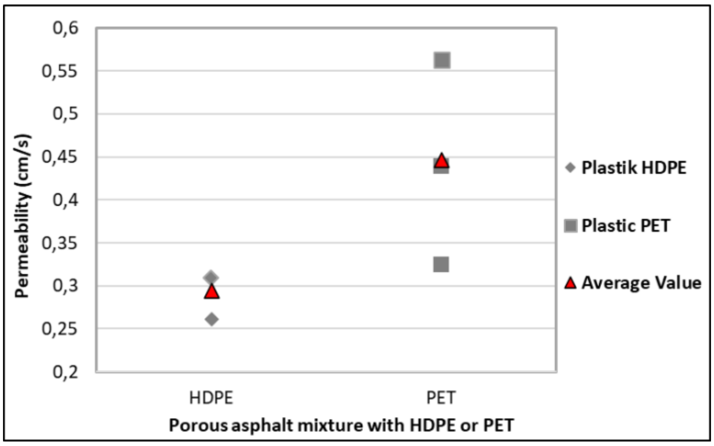


Figure 12. Graph of Permeability for Mixture 2 HDPE and Mixture 2 PET

Among the two plastic materials used as asphalt modifiers in the porous asphalt mixtures, PET provides better permeability performance than HDPE. The permeability value of the porous asphalt mixture with 2% PET as the modifier is 0.447 cm/second. Meanwhile, the mixture with 4% HDPE as the modifier has a permeability value of 0.294 cm/second.

4.4 Environmental Benefits of Using HDPE in Porous Asphalt Mixtures

The use of HDPE and PET plastics as partial asphalt modifiers in porous asphalt mixtures with an optimum plastic content of 4% for HDPE and 2% for PET based on the weight of asphalt material is shown in Table 11 regarding the assumed plastic requirement for road pavement over a length of 1 km:

Table 11. Assumed Requirements for HDPE and PET Plastic for 1 KM

Description	Mixture	Unit
Sample Weight	1150	gram
OAC	4,6	gram
Weight of Asphalt	52,9	gram
HDPE Plastic 1 Sample	2,116	gram
PET Plastic 1 Sample	1,058	gram
Specific Weight of HDPE 4% Asphalt Mixture	1,938	gr/cm^3

Specific Weight of PET 2% Asphalt Mixture	2,513	gr/cm^3
Plastic Requirements for 1 KM of Road		
Road Thickness	10	cm
Road Width	500	cm
Road Length	100.000	cm
Road Volume	500.000.000	cm^3
Total Weight of HDPE Asphalt Mixture	968.921.380	gram
Total Weight of PET Asphalt Mixture	1.256.500.000	gram
HDPE Plastic Requirement for 1 Km of Road	1.783	kg
PET Plastic Requirement for 1 Km of Road	1.156	kg

Based on these calculations, the plastic needed for 1 km road is 1,783 kg for HDPE and 1,156 kg for PET. Utilizing HDPE or PET plastics can be an option to reduce the demand for asphalt and help decrease environmental pollution.

5. DISCUSSION

HDPE and PET have high melting points, with PET melting at 220ºC and HDPE at 260ºC. This makes the mixing process more challenging. Adding plastic flakes after heating the asphalt and aggregate mixture allows better bonding even if the plastic does not completely melt. Melting the plastic first before mixing with asphalt and aggregates causes asphalt to boil, changing its characteristics and making it unsuitable for mixture.

For improving stability, HDPE is recommended as an asphalt modifier. For enhancing permeability, PET is preferred. Porous asphalt with 4% HDPE modification shows a stability value of 815 kg, which exceeds the minimum stability requirement for wearing course in Bina Marga specifications. Similarly, porous asphalt with 3% PET modification shows stability of 822 kg.

Using HDPE can save asphalt costs amounting to Rp.16,000 x 1,783 kg = Rp. 28,528,000 per kilometer, while PET usage saves Rp.16,000 x 1,156 kg = Rp. 18,496,000. However, labor costs for cleaning and cutting HDPE or PET are estimated at Rp. 1,250,000 per kg for 5 workers, leading to Rp. 2,228,750,000 for HDPE and Rp. 1,445,000,000 for PET per km. These high labor costs suggest the need for machines to process plastic pellets.

Future research could explore using fly ash as filler in HDPE porous asphalt to improve permeability, and in PET porous asphalt to improve stability.

6. CONCLUSION

Based on tests of normal porous asphalt mixtures and mixtures modified with plastic as asphalt modifiers, the conclusions are:

1. The VIM (Voids in Mix) value for mixture 1 (normal) and mixture 2 (with plastic modifier) at optimal plastic content is good and meets standards at 22.9%. The permeability results also meet standards: 0.330 cm/s for mixture 1, 0.294 cm/s for mixture 2 HDPE, and 0.447 cm/s for mixture 2 PET. These parameters show that each mix type effectively allows water flow as intended.

2. HDPE-modified mixtures produce higher average stability values than PET-modified mixtures. PET-modified asphalt delivers better permeability than HDPE-modified asphalt.
3. For mixture 2 with HDPE as modifier, optimum HDPE content is 4% with stability 815 kg, VIM 22.99%, flow 5.44 mm, MQ 149.82 kg/mm, and permeability 0.294 cm/s.
4. For mixture 2 with PET as modifier, optimum PET content is 2% with stability 751 kg, VIM 22.99%, flow 5.07 mm, MQ 148.64 kg/mm, and permeability 0.447 cm/s.

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