Journal PROKONS
Volume 20, Number 1 (February 2026) doi:10.33795/Prokons
ISSN : 1978-1784 (p); 2714-8815 (e)
https://jurnal.polinema.ac.id/index.php/PROKONS/

Submitted: 2026-01-16
Revised: 2026-02-22
Accepted: 2026-02-26

THE EFFECT OF HDPE PLASTIC WASTE SUBSTITUTION FOR SAND IN AC-WC TYPE ASPHALT CONCRETE MIXTURE ON MARSHALL CHARACTERISTICS AND OAC VALUE

Najla Nurrahma Amalia[1], Qomariah[2]

[1,2]Departement of Civil Engineering, Politeknik Negeri Malang, Jl. Sukarno-Hatta No. 9 Malang 65141, Indonesia

*Corresponding Author: qomariah@polinema.ac.id

ABSTRACT

The use of HDPE (High Density Polyethylene) plastic waste as a substitute material for sand in asphalt concrete has the potential to enhance the durability of asphalt. This aims to reduce the total amount of plastic waste around us, which is predominantly generated form household waste. One of the components of asphalt concrete that can be substituted with HDPE is fine aggregate. This research was conducted at the Materials Testing Laboratory, Civil Engineering Building, Politeknik Negeri Malang. The Marshall method was used with a total test specimens of 27. There are 15 specimens of normal asphalt with asphalt content variations of 4,5%; 5%; 5,5%; 6%; and 6,5%. And 12 specimens substituted with HDPE plastic variations of 0%, 2%, 4%, and 6%. From these tests, stability, flow, VIM, VMA, VFB, and KAO will be obtained. The stability for the 0% HDPE plastic variation is 1862.50 kg, and for 2% plastic is 2133,13 kg. This shows an approximate 14% increase in stability from 0% to 2% plastic. The flow for the 2% plastic substitution increased by about 5% from the 0% plastic. Based on the experiments, asphalt stability increases with higher plastic substitution levels. It can be concluded that substituting plastic in asphalt concrete mixtures enhances Marshall parameters and reduces the use of asphalt as a binding agent.

Keywords: HDPE, flow, stability, OAC

Introduction

The road is a land transportation infrasctructure that encompasses all component of the road, including ancillarry and supporting structures designed for traffic. Roads are infrastructure used for the mobilization of society. Therefore, roads must meet quality standards in terms of strength, comfort, and safety. Road planning must align with road pavement regulations, and maintenance must be considered to prevent rapid deterioration. This study investigates HDPE plastic waste as an additive material in road pavement. In addition, this research aims to serve as a reference in the field of road pavement that can utilize waste as construction material. According to Khadafi et al (2023), the utilization of HDPE plastic can improve Marshall characteristic, with the highest Marshall stability occurring at a plastic content of 5%. According to Budi Santoso et al (2023), adding 4% HDPE plastic to the Laston mixture can increase the retained stability and meet the Marshall specifications. HDPE (High-Density Polyethylene) waste is a type of plastic from the polyethylene (PE) family that has high density, good strength, and resistance to various chemicals and environmental conditions, including high temperatures. The advantage of this research is to explore the possibility of optimally utilizing HDPE plastic waste. In other words, HDPE plastic waste can substitute the role of fine aggregate, albeit modestly, and can reduce existing waste while hoped to improve Marshall characteristics in asphalt mixtures.

The focus of this study is on the utilization of HDPE plastic waste as a substitution for fine aggregate within the Laston AC-WC mixture. The study aims to :

1. Analyze the physical properties of agregates and asphalt to create Laston AC-WC mixtures with HDPE waste subtitution;
2. Determine the KAO value for the control specimens prior to the addition of HDPE waste as a substitution for the fine aggregate retained by a sieve size of 2.36 mm;
3. Analyze the effect of HDPE waste substitution at

contents of 0%, 2%, 4%, and 6% on the total weight of fine aggregates within the Laston AC-WC.

Materials and Methods

Place of Research

The research was conducted at the Road Materials and Asphalt Testing Laboratory, Civil Engineering Department, Politeknik Negeri Malang, Jl. Soekarno Hatta No. 9, Malang, East Java.

Flexibel Pavement

Flexible pavement is the asphalt concrete layer composed of coarse aggregate, fine aggregate, filler, and hot asphalt as a binder. The flexible pavement commonly applied in Indonesia is asphalt concrete.

1. Coarse aggregate with a percentage of 30–40%. The coarse aggregate used in mix design is retained on sieve No. 8 (2.36 mm) and must be clean, hard, durable, and free from clay or other undesired materials.
2. Fine aggregate with a percentage of 40–50%. Fine aggregate from any source should consist of sand or crushed stone screenings and should pass sieve No. 8 (2.36 mm) in accordance with SNI 03-6819-2002.
3. Filler with a percentage of 4–10%. The filler added can be Portland cement or other materials such as lime, or fly ash. The material must be free from undesired substances. Stone dust and the added filler must be dry and free of lumpiness. When tested by sieving according to SNI 03-4142-1996, it must contain not less than 75% passing sieve No. 200 (0.075 mm) of the material passing sieve No. 30 (0.600 mm). The filler should exhibit non-plastic characteristic.
4. Asphalt cement with a percentage 0f 0-10%.

The layers in road pavement serve to support and distribute traffic loads to the subgrade. The road pavement structure consists of the surface course (wearing course) and the intermediate layer. The lower layer is the base course. The subbase course, and the subgrade.

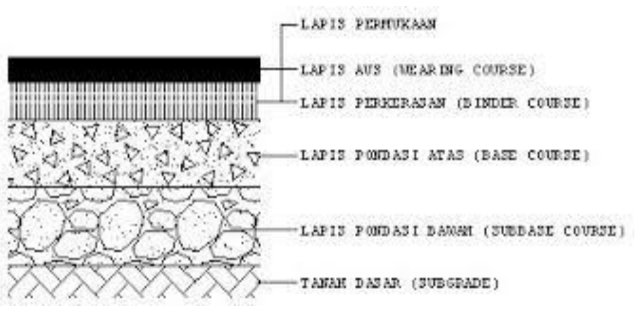

Figure 1. Flexibel Pavement Layers

The layer is placed on the subgrade. To meet the strength requirements of each layer, the material specifications for asphalt concrete mixtures are as follows :Specific gravity of coarse aggregate (Ø5 mm – 20 mm) for asphalt concrete, minimum 2.5 g/cm$^{3.}$

1. Specific gravity of fine aggregate (Ø0.15 mm – 4.75 mm) for asphalt concrete, minimum 2,5 g/cm^3.
2. Specific gravity of filler (Ø0.075 mm) for asphalt concrete: 2.5–3.15 g/cm^3.
3. Abrasion value of coarse aggregate: < 25%.
4. Abrasion value of fine aggregate: < 25%.
5. Hardness value of coarse aggregate: <5%.

The abrasion values of both coarse and fine aggregates are crucial to monitor because this layer directly bears heavy vehicle loads. If the abrasion value exceeds 25%, the material is not suitable for flexible pavement. Additionally, the hardness value of coarse aggregate is required to be < 5% for flexible pavement to withstand the imposed vehicle loads.

Asphalt Cement

Asphalt is defined as a black or dark brown material, solid to fairly solid at room temperature. Bitumen (asphalt cement) binds aggregates in asphalt concrete mixtures, provides a waterproof layer, and is resistant to acids, bases, and salts. The asphalt used in road pavement materials serves as :

1. A binding agent, providing a strong bond between asphalt and aggregates and among asphalt itself.
2. A filling agent, filling the voids between aggregate particles and the pores present within the aggregate itself.

Plastic

Plastic is a long-chain polymer of atoms that bond to one another. This chain forms many repeating molecular units, or “monomers.” Plastic can be shaped into films or synthetic fibers. Plastics are designed with a very wide variation in properties that tolerate heat, hardness, and “rigidity.” Plastics are almost used across nearly all sectors of industry.

HDPE *(High Density Polyethylene)*

One type of plastic is HDPE (High-Density Polyethylene). According to Dean McClements (2022), High Density Polyethylene (HDPE for short) is a thermoplastic polymer produced from petroleum and is generally represented by the chemical formula $(C_2H_4)n$. HDPE is a type of plastic that is safe because it has properties that resist high temperatures. It is used for baby bottles, Tupperware, and drinking water jugs. It is not recommended to be used repeatedly.

Testing the Physical Properties of Agregates

1. Water content test. The purpose of this test is to determine the ratio between the weight of water contained in the aggregate and the dry weight of the aggregate.

2. Bulk specific gravity and absorption test of aggregates. The purpose of this test is to determine the ratio of solid mass to water mass at the same volume and temperature for coarse and fine aggregates. Meanwhile, aggregate absorption aims to determine the aggregate's ability to absorb water from the dry condition to the surface-dry saturated (SSD) condition.
3. Aggregate grading test. The purpose of this test is to determine the distribution or spread of particle sizes of both coarse and fine aggregates.
4. Aggregate wear test. The purpose of this test is to determine the resistance or strength of coarse aggregate to wear using a Los Angeles machine.
5. Aggregate hardness. The purpose of this test is to determine the durability of coarse aggregate against damage due to use in construction.
6. Organic content. The purpose of this test is to determine the content of organic materials present in fine aggregate.

Testing the Physical Properties of Asphalts

1. Penetration test. The purpose of this test is to determine the consistency or penetration (viscosity) of asphalt using a penetrometer.
2. Softening point test. The purpose of this test is to determine the temperature range at which asphalt can be spread and remain stable without melting due to heat.
3. Bulk density test. The purpose of this test is to determine the bulk density (relative density) of asphalt to be used in asphalt concrete mix.

Testing of Asphalts Concrete Mixtures

Hot-mixed asphalt concrete test to determine Marshall characteristics of the mixture, including density, maximum bulk density of the mixture, air voids in the mixture (VIM), asphalt-void content (VFA), voids in mineral aggregate (VMA), stability, flow, Marshall Quotient (MQ) as required in RSNI M-06-2004, focus only on three Marshall characteristic values : stability, flow, MQ.

Stability

Surface layer stability of the road pavement is the ability of the pavement layer to withstand traffic loads without undergoing permanent deformation such as waves, ruts, or bleeding. Stability occurs due to inter-particle sliding, locking between particles, and good bonding within a layer of asphalt. High stability can be achieved by using closely graded aggregates, aggregates with a rough texture, cubical-shaped aggregates, asphalt with low penetration values, and sufficient asphalt content to bond between particles. On the other hand, excessively high stability causes the layer to become stiff and prone to cracking quickly. Conversely, because the inter-aggregate void volume is small, the asphalt content requirement is low.

Based on RSNI 03-1737-1989 and the Guidelines for the Implementation of Asphalt Mixtures Layer (2007), regarding the properties of asphalt mixture, the minimum stability value for wearing course (WC) and base course (BC) layers is greater than 800.

Flow

Flow or deformation is the amount of settlement or deformation that occurs in asphalt concrete layers when bearing loads applied from above. The flow value affects the flexibility of the mixture. A high flow value with low stability indicates a high flexibility of the mixture. If the flow value is low and the stability value is high, this indicates that the mixture is stiff and brittle. Conversely, a mixture with a high flow value and low stability shows plastic behavior, meaning the mixture is prone to deformation when subjected to a load.

Marshall Quotient

The Marshall Quotient (MQ) value is stated in units of kg/mm. In RSNI 03-1737-1989 and the Guidelines for the Implementation of Hot Asphalt Mixture Layers (2007) regarding the properties of asphalt concrete mix, the MQ value for Laston (asphalt concrete) properties is greater than 250 kg/mm. A high MQ value indicates that the mixture is very stiff and brittle.

Gradation

Aggregate grading is the distribution of aggregate sizes, typically shown by the arrangement of particles ranging from the smallest to the largest size used. The aggregate gradation in asphalt concrete mixtures will influence the resulting mixture stability.

VIM (Void in Mixture)

Voids formed between aggregate minerals and asphalt after compaction. These voids willmake it easier for water to penetrate the pavement layer and causeaggregate to separate from the binding material.

VFA (Asphalt-void Content)

The void formed between the filler, sand, and gravel. Asphalt can fill this void to increase stability and reduce VIM.

VMA (Void in Mineral Aggregate)

The voids formed between sand and sand, sand and gravel, gravel and gravel, gravel and filler. These voids can be covered with asphalt and melted HDPE plastic. This improves the bond between the gravel, sand, and filler to increase the bearing capacity or Marshall stability.

Marshall Gradation IV Test Specimen Mix Design

Table 1. Results Analysis of Grading IV of Asphalt Concrete Mixture

Diameter	% retained	Test Object I	Test Object II	Test Object III	Test Object IV	Test Object III
19	20	228	226,8	225,6	224,4	223,2
12,5	13	148,2	147,42	146,64	145,86	145,08
9,5	10	114	113,4	112,8	112,2	111,6
4,75	10	114	113,4	112,8	112,2	111,6
2,36	10	114	113,4	112,8	112,2	111,6
1,18	8	91,2	90,72	90,24	89,76	89,28
0,6	7,5	85,5	85,05	84,6	84,15	83,7
0,3	7,5	85,5	85,05	84,6	84,15	83,7
0,15	7	79,8	79,38	78,96	78,54	78,12
0,075	7	79,8	79,38	78,96	78,54	78,12

Source : Table 2 SNI 03-1737-1989

Based on RSNI 03-1737-1989, and the gradation IV limits that have been analyzed from the table above, the approximate asphalt content is calculated using the following formula :

$$\begin{aligned} Pb &= 0{,}035(\%CA) + 0{,}045(\%FA) + 0{,}18(\%FF) + k \\ &= 0{,}035(53) + 0{,}045(40) + 0{,}18(7) + 0{,}5 \\ &= 0{,}5415 = 5{,}415 \text{ then rounded to } 5{,}5\% \end{aligned}$$

Notes :

Pb	=	Initial planned asphalt content to mixture weight
FA	=	Total percentage of fine aggregate retained
FF	=	Filler material
CA	=	Total percentage of retained coarse aggregate
K	=	Constanta, range 0,5

From the above formula, the obtained result is still an approximation. The result will be rounded to approximately 0.5% using three asphalt contents above the estimated content and two asphalt contents below the estimated content. Therefore, the asphalt contents used are 4.5%; 5%; 5.5%; 6%; and 6,5%.

Marshall Testing

Marshall testing is an examination conducted to determine the Marshall characteristics of asphalt concrete mixtures. The Marshall test is performed after the test specimen is removed from the mold at age of one day. A volumetric study is then conducted, including :

1. Measurement of the specimen height;
2. Measurement of the specimen diameter;
3. Weighing the specimen (in air, surface saturated and drained - SSD, or equivalent);
4. Weighing the specimen in SSD condition after drying, if applicable;
5. Weighing the specimen immersed in water.

After the volumetric tests are completed, the specimens are immersed in water preheated to 60°C for 30 minutes to obtain the maximum stability and flow values. Once these values are obtained, VIM (Void in Mineral Aggregate), VMA (Voids in Mineral Aggregate), VFB (Void-Filled Bitumen), and MQ (Marshall Quotient) can be calculate

Table 2. Asphalt Concrete Layer Mixture Requirement

Mixed Characteristic		Laston WC	Laston BC	Laston Base
Number of impacts per surface		75		122
Asphalt absorption, %	Max		1,2	
Voids in Mixture (VIM) %	Min		3,5	
	Max		5,5	
Voids in Mineral Agregat (VMA) %	Min	15	14	13
Voids Filled with Asphalt (VFA) %	Min	65	63	60
Marshall Stability (kg)	Min	800		1500
Flow (mm)	Min	3		5
Marshall Quotient, kg/mm	Min	250		300
Residual Marshall Stability (%) after soaking 24 hours, 60°C on VIM ±7%	Min		80	
VIM at spherical density (refusal) %	Min		2,5	

Source : Analysis Result

Result and Discussion

Coarse Agregate Test Result

From the coarse aggregate test, it was found that aggregates meeting the specifications of SNI 03-1737-1989 can be seen in **Table 3.**

Tabel 3. Results of Coarse Aggregate Testing

Type of Testing	Unit	Result	Specification	Standard
Bulk Specific Gravity	gram/cm^3	2,645	Min 2,5	SNI 03-1738-1989
SSD Specific Gravity	gram/cm^3	2,691	Min 2,5	SNI 03-1738-1989
App Specific Gravity	gram/cm^3	2,773	Min 2,5	SNI 03-1738-1989
Water Absorption	%	1,747	Max 3%	SNI 03-1738-1989
Abrasion	%	15,96	Max 25%	SNI 03-1738-1989
Hardness	%	5,39	Max 25%	SNI 03-1738-1989

Source : Analysis Result

Fine Agregat Test Result

From the fine aggregate test, it was found that the fine aggregates meeting the specifications of SNI 03-1737-1989 can be seen in **Table 4.**

Table 4. Result of Fine Agregate Testing

Type of Testing	Unit	Result	Specification	Standard
Bulk Specific Gravity	gram/cm^3	2,668	Min 2,5	SNI 03-1738-1989
SSD Specific Gravity	gram/cm^3	2,695	Min 2,5	SNI 03-1738-1989
App Specific Gravity	gram/cm^3	2,741	Min 2,5	SNI 03-1738-1989
Water Absorption	%	1,005	Max 3%	SNI 03-1738-1989
Clay Content in Sand	%		Max 8%	SNI 03-6877-2002
Clay Content in Gravel	%		Max 1%	SNI 03-6877-2002

Source : Analysis Result

Asphalt Test Result

From the asphalt test, it was found that the aggregates meeting the specifications of SNI 03-1737-1989 can be seen In **Table 5.**

Tabel 5. Result of Testing Asphalt

Testing	Test Result	Regulations		Test Method
		Min	Max	
Penetration (25°C)	62,69	60	70	SNI 2456-2011
Titik Lembek, °C	48	48°C	58°C	SNI 2434:2011
Berat Jenis	1,033	1,0	-	SNI 2441:2011

Source : Analysis Result

Mixture Design For The Test Speciment

Based on the aggregate composition, using Gradation IV and varying asphalt content, 15 normal test specimens will be prepared. For each asphalt content variation, three test specimens will be produced. The asphalt content variations used are 4,5%; 5%; 5,5%; 6%; and 6,5%. Additionally, 12 test specimens will be prepared with HDPE plastic substitution at 0%; 2%; 4%; and 6%. These will be used to determine the Marshall characteristic values.

Testing Using a Normal Test Speciment Marshall

Summary of the Marshall test results for the AC-WC dense asphalt concrete pavement mixture with asphalt contents ranging from 4,5% to 6,5%, concerning VIM, VMA, VFA, stability, flow, and MQ, can be seen in Table 6.

Tabel 6. Recapitulation of Marshall Testing for Asphalt Concrete Mixtures

Marshall Parameters	Specification	Asphalt Content				
		4,5%	5%	5,5%	6%	6,5%
Stabilitas (kg)	Min 800	1180	1340	1200	1250	1100
VIM (%)	Min 3,0%	4,87	3,97	3,7	2,6	3,6
VMA (%)	Min 14%	15	15,5	16	15,25	16,5
VFA (%)	Min 65%	68	72	78	80	85
Flow (mm)	Min 2	3,2	3,5	3,7	3,8	3,9
MQ (kg/mm)	Min 250	368,75	382,85	324,32	328,94	282,05

Source : Result of Testing Marshall

Marshall Testing With HDPE Plastic Waste Subtitution

The next step is to prepare test specimens in which HDPE plastic waste substitutes a portion of the fine aggregate, with plastic content variations of 0%, 2%, 4%, and 6% relative to the total fines retained on No. 8 sieve. The Marshall test results for these specimens can be seen in **Table 7.**

Tabel 7. The Summary of Marshall Tests on Test Specimens Substituted with Various HDPE Plastic Waste Content Levels

Mixed Characteristic AC-WC	Specification	Subtitution Content of HDPE (%)			
		0%	2%	4%	6%
Stabilitas (kg)	Min. 1000	1862,50	2133,13	2942,07	3481,22
VIM (%)	2,0 - 4,0	2,01	2,13	2,03	3,91
VMA (%)	3,0 - 5,0	4,87	4,71	4,85	5,0
VFA (%)	Min. 14	14,75	15,94	17,09	18,47
Flow (mm)	Min. 65	67,14	70,46	71,66	71,39
MQ (kg/mm)	Min. 250	1003,84	1289,30	1843,33	1191,08

Source : Marshall Test Result

Determination Of The Optimum Asphalt Content (OAC)

From the Marshall test results for the asphalt concrete layer specimens without HDPE plastic waste substitution, as shown in Tables 6 and 7, the Marshall characteristics can be determined. Next, the Optimal Asphalt Content (KAO) is the asphalt content that meets the specified requirements for the other parameters. The optimum asphalt content obtained is 5%, as shown in **Picture 2.** The optimum asphalt content (KAO) for the asphalt concrete mixture with HDPE plastic substitution is 3%, as shown as **Picture 3.**

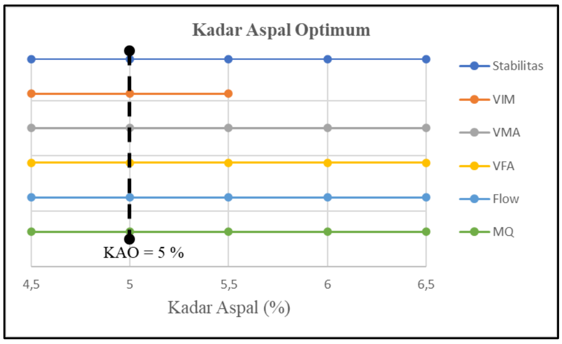

Figure 2. Optimum Asphalt Content Determination Chart (OAC) without Plastik HDPE Wate

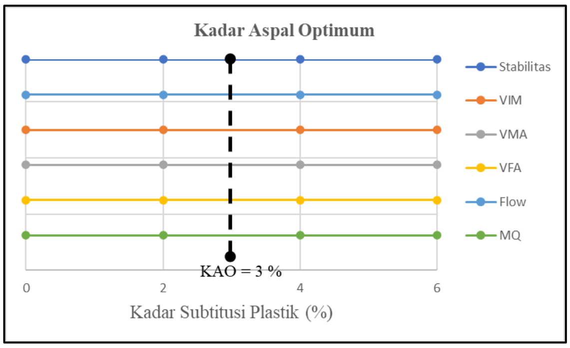

Figure 3. Optimum Asphalt Content (OAC) Determination Chart with HDPE plastic subtitution

The difference in the obtained Optimum Asphalt Content (KAO) values between plastic substitution and sand in the asphalt concrete mix shows a 40% reduction in the amount of asphalt. This indicates that asphalt concrete production can be engineered with HDPE plastic substitution in the sand as part of the aggregate. It also yields positive effects on the quality of the asphalt concrete mix, with increases in stability and flow.

Based on the study of substituting HDPE plastic waste as aggregate for fine aggregate, the following conclusions can be drawn:

1. The Optimum Asphalt Content (KAO) decreases with HDPE plastic substitution for sand. This indicates that the plastic characteristics in the asphalt concrete mixture improve Marshall parameters and reduce the consumption of asphalt as the binding material.
2. HDPE plastic waste is feasible to use as long as the requirements are met. Because the plastic's melting point is around 200 degrees Celsius and melted plastic does not show structural degradation but remains as a thin sheet, these sheets can assist the asphalt in bonding the aggregates and imparting strength. This is evidenced by higher stability values in asphalt concrete mixtures substituted with HDPE waste.
3. The amount of asphalt use can be minimize but the function of Marshall characteristic is achievable.
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