Performance of Porous Asphalt Mixture Using HDPE (High Density Polyethylene) Plastic Additives

M. Sa'dillah [1], Blima Oktaviastuti [2], Galih Damar Pandulu [3], Andy Kristafi Arifianto[4], Susana Rambu Ndima[5]

[1,2,3,4,5] Department of Civil Engineering, Tribhuwana Tunggadewi University, Indonesia

Article Info

Article history:

Accepted March 10, 2024
Approved April 10, 2024
Published April 29, 2024

Keywords:

HDPE, Marshall, Aspal Porous, Cantabro Loss, Asphalt Flow Down

ABSTRACT

Efforts are being made to increase the strength or stability of porous asphalt mixtures by adding HDPE plastic waste. The reason for making HDPE plastic added material is that it has the same properties as asphalt, namely thermoplastic has a penetration value equivalent to pen 60/70 asphalt. This study aims to: (1) Describe the characteristics of the constituent materials of porous asphalt mixtures and (2) The effect of adding HDPE plastic to porous asphalt mixtures was reviewed based on the Marshall Test, CL, and AFD. The research method uses experimental research in the laboratory. The research will be carried out using the AAPA 2004. The research was carried out with pen 60/70 asphalt content, 4%, 4.5%, 5%, 5.5%, and 6% to find the value of asphalt content. optimum, then will be added with a ratio of HDPE material 0%, 2%, 4%, 6% and 8% to the total weight of KAO. The results of the Marshall characteristic analysis for porous asphalt mixtures with varying levels of 2% HDPE have met the specifications on the grounds that all parameters have met the requirements of the AAPA 2004 with a VIM value at 2% content of 18.18%, for a VMA value of 29.40%, while stability value is 640 kg and flow value obtained is 2.30 mm while the MQ value is 284.63 kg/mm. CL test a value of 0.19% - 0.25%, this indicates that the test is still within the threshold, max of 0.3%. AFD test has a value of 6.21% – 6.90%, this test still meets the requirements because the max 35%.

Available online at http://dx.doi.org/10.36055/fondasi

Corresponding Author:

M. Sa'dillah,
Department of Civil Engineering,
Tribhuwana Tunggadewi University,
Jl Telaga Warna, Tlogomas, Kota Malang, 65144, Indonesia.
Email: muhsad93@gmail.com

1. INTRODUCTION

Waste is the residue of production from industrial and household activities. Currently waste is a common problem among the community. One of the wastes that can be found around the environment is plastic. Plastic is a material that is relatively non-degradable, so the utilization of plastic must be considered considering the amount of waste it produces [1]. According to [2], the amount of plastic consumption has continued to increase by 24.4% over a period of 4 years. The increasing consumption of plastic, the greater the amount of waste produced so that it will have an impact on humans and the environment. Loaded in CNNIndonesia.com (23/02/2016), according to data from the Ministry of Environment and Forestry (KLHK), plastic produced from 100 shops or members of the Indonesian Retailers Association (APRINDO) within 1 year has reached 10.95 million pieces of plastic bag waste. In addition, based on research [3], Indonesia is the second-ranked country in the world as a producer of plastic waste which reached 187.2 million tons after China which reached 262.9 million tons. The abundance of plastic waste is because plastic has properties that are light but strong, transparent, water resistant, and the price is relatively cheap and affordable by all people [2]. The large amount of plastic has the potential to cause ecological problems because plastic is non-degradable and renewable [4]

There are various types of plastic, one of which is often used is HDPE (High Density Polyethylene) plastic. According to [5] Roads with flexible pavements use asphalt as an aggregate binder so that they are in great demand than rigid pavements. Road infrastructure requires ongoing maintenance. The use of plastic packaging cannot be separated in everyday life. Based on the problem of the amount of used plastic waste that exists now, this research is needed to find out how well the pavement uses HDPE plastic types as mixed plastic waste. After testing in the laboratory and analyzing according to General Highway Specifications for a normal composition without 0% plastic admixture, the asphalt content that meets all requirements is estimated to be between 5.6% - 6%. One of the activities to reduce the problem of plastic waste is by making goods to support daily needs, namely recycling HDPE plastic into ashtrays, the results are uneven and there is still empty space in the printed output [6]. In addition to research using plastic, there are several studies related to the use of waste such as fly ash and used tire powder which are quite interesting to carry out more in-depth research [7]–[10]. According to [11] that hollow asphalt has low stability but high permeability due to the many cavities in the mixture, so other materials need to be added to increase the stability of the mixture. In the research conducted, the addition of plastic to road asphalt can cause gondorukem as a mixture of porous asphalt pavement to increase the strength value of the road due to excessive vehicle loads. Besides that, there are also other factors such as weather and standing water, with the development of porous asphalt technology, it has a mixture of hot asphalt with Open gradation hereby utilizes waste as an additive to porous asphalt. Porous asphalt is an asphalt mixture dominated by coarse aggregate and low sand content to obtain a high porosity value, designed to have a porosity value of more than 20%. High porosity asphalt mixtures have better characteristics than conventional asphalt mixtures. usually the durability is not high enough, this can be overcome by using polymer or fiber additives. [12] Porous asphalt or porous asphalt is a new pavement method currently being developed in the world of highway construction. Porous asphalt is an asphalt mixture that uses an open gradation with a coarse aggregate fraction ranging from 70-85% and fine aggregate ranging from 15-30% of the total weight of the mixture [13]. Porous asphalt has several advantages, including reducing surface water loads, reducing noise levels generated by vehicles, and not being dangerous for road users because porous asphalt has a high level of hardness (skid resistance), so the wheels do not slip easily when driving at high speed [14]. The use of porous asphalt can be used for moderate traffic such as rural roads, parking lots, or roads that have other moderate loads. In the Marshall test without the addition of plastic waste and HDPE plastic additives as well as Marshall for each material, the optimum asphalt content (KAO) value will be considered, from the Marshall test which includes Stability, Flow, VIM at the asphalt content which will be planned according to previous researchers to reach 5% [15]. Porous asphalt is seen to have a low stability value, is weather resistant and has cavities and pores and is resistant to inundation. According to [16] the research objectives in this study were (1) to determine the characteristics of the constituent materials of porous asphalt mixtures. (2) Knowing the effect of adding HDPE (High Density Polyethylene) plastic in the optimum mixture of porous asphalt on Marshall characteristics.

2. METHODS

This research is an experimental test on pore asphalt testing with HDPE (*High Density Polyethylene*) plastic additives. Asphalt 60/70 is asphalt that is generally used in Indonesia. The research was carried out in the Tribhuwana Tunggadewi University campus area (Transportation and Roads Laboratory). This type of research is quantitative research, because this research is a type of research whose specifications are systematic, planned, and clearly structured from the start to the research design. In this research, a certain duration of time is required, starting from the process of preparation, manufacture and testing of pore asphalt. In a study so that the expected goals are achieved, it is necessary to study the materials related to the title of the final project. So this can be obtained by studying books, laboratory data and information from the internet. To make it easier to identify and solve each problem and produce appropriate output, a research flowchart has been prepared.

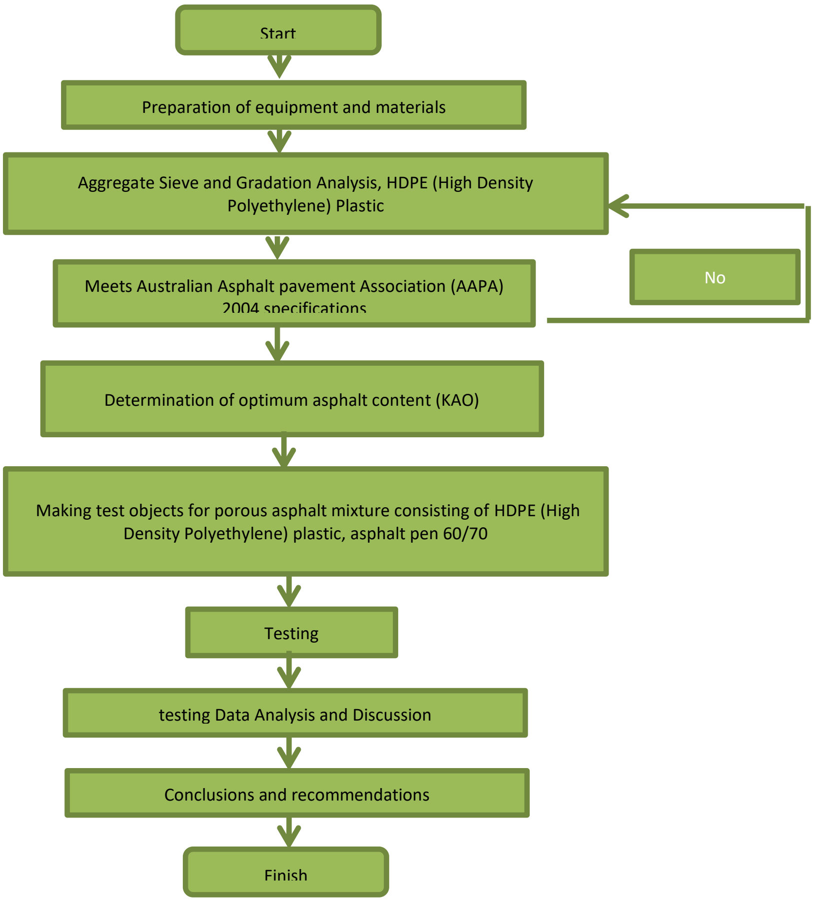

Figure 1 Research Flowchart

The aggregate grading plan used is based on the 2004 Australian Asphalt Pavement Association (AAPA) specifications.

Table 1 Aggregate gradation of porous asphalt mixture [17]

No Sieve	Sieve Size (mm)	Specification	% Slip	% Restrained	Weight (gr)
¾	19,0	100	100	0	0
½	13,2	85-100	90	10	120
3/8	9,5	45-70	58	32	384

No Sieve	Sieve Size (mm)	Specification	% Slip	% Restrained	Weight (gr)
No. 4	4,75	10-25	17	41	492
No. 8	2,36	7-15	11	6	72
No. 16	1,18	6-12	9	2	24
No. 30	0,6	5-10	7	2	24
No. 50	0,3	4-8	6	1	12
No. 100	0,15	3-7	5	1	12
No. 200	0,075	2-5	3	2	24
PAN	0	0	0	3	36
Total Weight					**1200**

Asphalt used in this study is hard asphalt with a penetration of 60/70. This test is based on the AAPA 2004 specifications.

Table 2 Asphalt characteristic test specifications [17]

No	Testing	Unit	Specification		Unit
			min	maks	
1	Penetration	mm	60	79	Mm
2	Soft Point	° C	48	58	° C
3	Flash point	° C	200	-	° C
	Burn point	° C	200	-	
4	Specific gravity	gr/cm3	1	-	
5	Ductility	cm	100	-	

This research was carried out by making test specimens and analyzing the results of the research, the research design was made so that researchers had a basis for material requirements and the number of test objects needed.

Table 3 *Mix Design*

No	Test Object Code	Optimum Asphalt Content (%)	Weight KAO (gr)	Level HDPE (%)	Weight HDPE (gr)	Number of Test Objects (unit)	Total HDPE (gr)
1	PL.0	5,00	60	0%	0,00	6	0,00
2	PL.2	5,00	60	2%	1,20	6	3,60
3	PL.4	5,00	60	4%	2,40	6	7,20
4	PL.6	5,00	60	6%	3,60	6	10,80
5	PL.8	5,00	60	8%	4,80	6	14,40
Total Amount of KAO						**30**	**-**
Total Marshalls						**30**	**72,00**
Total *Cantabro Loss*						**7**	**72,00**
Total *Asphalt Flow Down*						**7**	**72,00**
Total Overall Test Objects						**75**	**216,00**

Cantabro Loss (CL) test is carried out in order to determine the strength of asphalt in the inspection concept by releasing granules with open gradations. This test object is a test object that is left for one night, then taken out. With this, the test object will be moved for 7 days before being put into the Los Angeles machine and rotated the specified number of 500 rotations without using a steel ball.

Asphalt Flow Down (AFD) testing with this test is to determine the optimum asphalt content (KAO) which can be mixed homogeneously with aggregate without separating the asphalt. Asphalt Flow down asphalt testing as follows:[2]

a) The mold has dimensions of 20 x 30 cm and is covered with paper, with this the weight of the mold is weighed.
b) Make 1200 grams of asphalt mixture and after mixing it evenly, pour it directly into the mold, cover it with paper and record the value.
c) The mold is placed in the oven at 170°C for 1 hour
d) The procedure is repeated according to the procedure.
e) Next, the mold is removed from the oven and the asphalt mixture is quickly poured in and with the weight of the mold attached to the aggregate, then weighed and the value recorded.

Determining Optimum Asphalt Content (KAO) using the Australian Asphalt Association (2004) method, the KAO value will appear using this method requiring several parameters of cantabro loss, asphalt flow down, VMA, KAO, MQ and stability. With this, the stages are as follows:
a) The void content in the mixture is 20% to obtain maximum asphalt content.
b) Maximum Cantabro loss value of 20% to obtain minimum asphalt content
c) Asphalt content is obtained from the minimum and maximum asphalt content
d) Plotting asphalt content in the form of an asphalt flow down graphic diagram

Regression analysis is used to determine the relationship pattern or relationship between the dependent variable and the independent variable. The use of this regression line was chosen because this regression analysis model is considered very strong and flexible because it can correlate a large number of independent variables with the dependent variable. A dependent variable and independent variable have a significant correlation which is tested through the probability of alpha error. The variable that is predicted is called the criterion and the variable that is used to predict is called the predictor. The correlation between the criterion variable and the predictor variable can be described in a regression line. The regression line being analyzed is a linear regression line expressed in a mathematical equation called the regression equation. The main tasks of regression analysis are:

1. Looking for correlations between criteria and predictors
2. Test whether the correlation is significant or not
3. Look for the regression line equation
4. Finding the relative contribution between predictors if there is more than one predictor [18]

$$y = a + bx \text{……………………(i)}$$

Information:
y = asphalt content value
x = plastic content value

The regression line equation is obtained from a set of data which is then arranged into a scatter diagram. From this diagram, with the help of Microsoft Excel, a linear regression line can be made, then from the regression line, the regression equation and the coefficient of determination are obtained.In the band diagram method, the results of research in the laboratory, namely the Marshall test parameters (VIM, VMA, stability, flow, MQ) as the Y axis are plotted with the variation of asphalt content tested as the X axis. optimum asphalt content (KAO) was obtained. Likewise, by obtaining the proportion of plastic content, the Marshall test parameters (Y axis) were plotted with variations in the proportion of plastic content tested (X axis).

3. RESULTS AND DISCUSSION

The research results are explained in full according to the method used. An in-depth discussion is carried out based on data from surveys, tests, or other data collection methods. The discussion must relate the content to the theory that has been put forward before. In the event that a lot of result data is displayed, Results and Discussion/Analysis can be listed in different sections. The results of aggregate testing in the laboratory that will be used must meet the specifications of the Australian Asphalt Pavement Association (AAPA) 2004 to be used as a road pavement material for porous asphalt mixtures.

Table 4 Coarse and Fine Aggregate Test Results

No	Testing	Units	Specification *		Results	Information
			Min	Max		
			Coarse Aggregate			
1	BJ Bulk	(gr/cm^3)	2,5	-	6,51	Passed
2	BJ SSD	(gr/cm^3)	-	-	6,54	Passed
3	BJ Semu	(gr/cm^3)	-	-	6,70	Passed
4	Absorption	%	-	3,0	0,45	Passed
5	Wearout	%		40	20,06	Passed
			Fine Aggregate			
1	BJ Bulk	(gr/cm^3)	2,5	-	6,56	Passed
2	BJ SSD	(gr/cm^3)	-	-	6,56	Passed
3	BJ Semu	(gr/cm^3)	-	-	6,44	Passed
4	Absorption	%	-	3,0	2,16	Passed

If the asphalt material does not meet the predetermined specifications, it can reduce the performance of the porous asphalt mixture in supporting the vehicle load on it.

Table 5 Asphalt Testing Results

No	Testing	Units	Specification *		Results	Information
			Min	Max		
1	Specific gravity	(gr/cm^3)	1	-	1,034	Passed
2	Penetration	(mm)	60	79	66,70	Passed
3	Soft Point	(˚C)	48	58	55	Passed
4	Flash point	(˚C)	200	-	265	Passed
5	Burn point	(˚C)	200	-	285	Passed
6	Ductility	(cm)	100	-	240	Passed

Determination of the optimum asphalt content is determined from the relationship between several parameters of the porous asphalt test with the required standards. Asphalt content of 4%, 4.5%, 5%, 5.5% and 6% all meet the specifications specified by the Australian Asphalt Pavement Association (AAPA) 2004. From taking the median value that meets these specifications, it can be concluded that the porous asphalt mixture meets marshall characteristics and has an optimum asphalt content of 5%. The HDPE content test that has been carried out obtained the parameters namely VIM, VMA, stability, flow, and marshall quotient.

Table 6 Test Results for HDPE Levels

No	Testing	Units	specification *		Results
			Min	Maks	
1	*VIM*	(%)	18	25	6,79 – 21,11
2	*VMA*	(%)	-	15	25,99 – 34,84
3	Stability	(kg)	500	-	203,61 – 949,31
4	*Flow*	(mm)	2	6	1,52 – 3,00
5	*Marshall Quotient*	(Kg/mm)	400	-	67,87 – 667,52

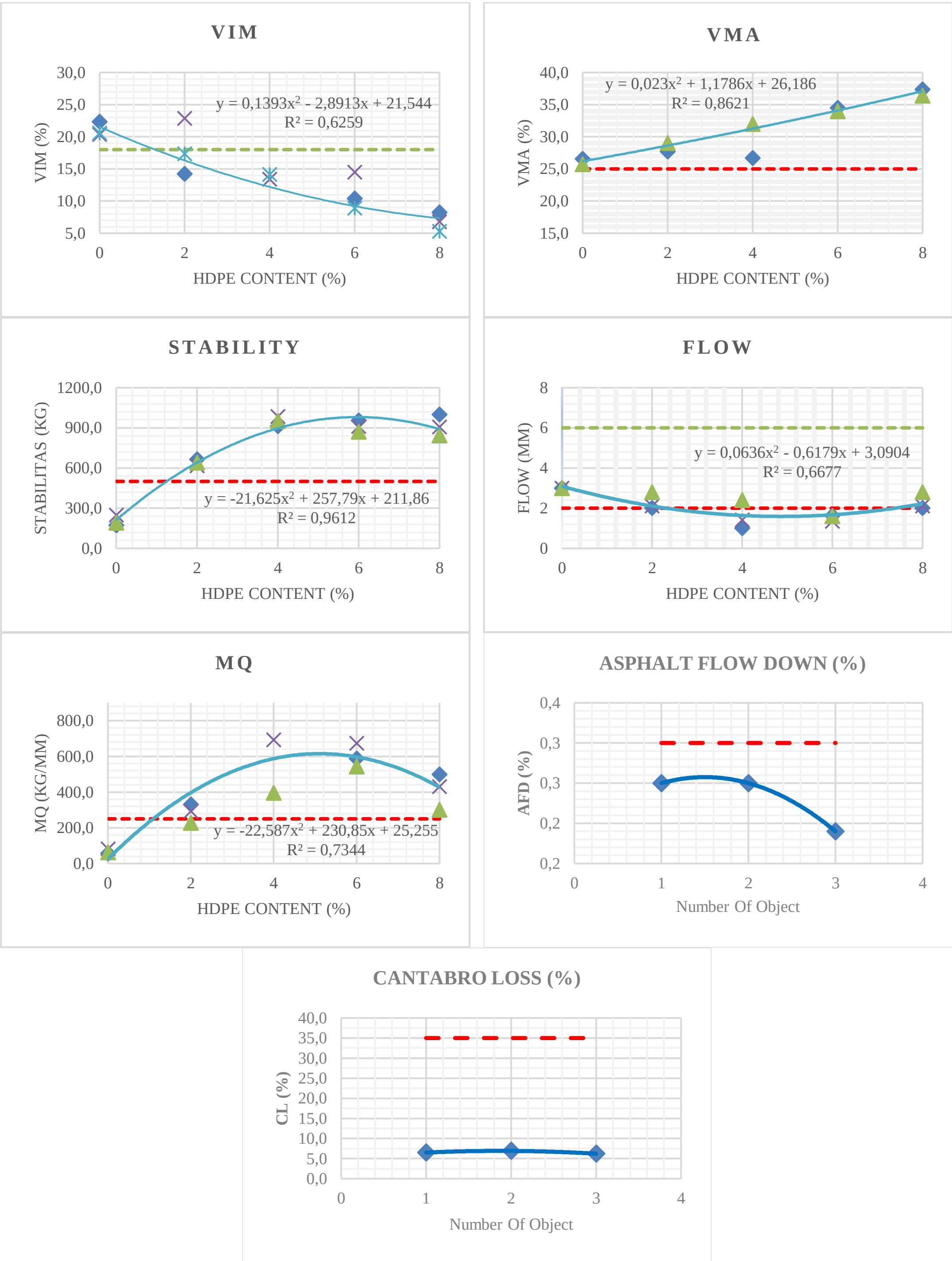

Figure 2 Test Results for HDPE Levels

Parameter Marshall	Specification	Test result			HDPE level (%) 0	2	4	6	8
VIM (%)	18 - 25	6,79	-	21,11					
VMA (%)	15	25,99	-	34,84					
Stability (Kg)	Min. 500	203,61	-	949,31					
Flow (mm)	2 - 6	1,52	-	3,00					

Parameter Marshall	Specification	Test result			HDPE level (%)				
					0	2	4	6	8
MQ (Kg/mm)	Min 250	67,87	-	667,52					
AFD (%)	Max 0,3	0,19	-	0,25					
CL (%)	Max 35	6,21	-	6,90					

Figure 3 Diagram Band for Determining HDPE Levels

VIM or Void in Mix is the pore volume that remains after the asphalt mixture is compacted and is needed for the shifting of aggregate grains. The VIM value affects the durability of the pavement layers. The higher the VIM value indicates the greater the cavity in the mixture so that the mixture is porous. And if the VIM value is too low it will cause bleeding. According to [11] the VIM value generally decreases with increasing asphalt content. This is comparable to research [19] adding coal fly ash content makes the VIM value decrease at the optimum mixed content of 7% with a value of 4.69%. The VIM value in the 0% and 2% HDPE content test fulfills the requirements for the VIM value in porous asphalt mixtures which are 18 - 25%. In general, the more HDPE is added, the VIM value will decrease, this indicates that HDPE fills the voids in the aggregate.

VMA or Void in Mineral Aggregate is the pore volume that remains after the asphalt mixture has been compacted and is needed for places to shift aggregate grains. VMA value affects the durability of pavement layers. The higher the VMA value indicates the greater the cavity in the mixture so that the mixture is porous. And if the VMA value is too low it will cause bleeding. According to [11] the VMA value generally decreases with increasing asphalt content. For all asphalt content, the VMA value meets the specification requirements of the Australian Asphalt Pavement Association (AAPA) 2004, the requirement for a VIM value for porous asphalt mixtures is > 15%.

The value of stability is influenced by shape, quality, surface texture and aggregate gradation, namely friction between aggregate grains (internal friction) and interlocking between aggregates (interlocking), adhesion (cohesion), and asphalt content in the mixture. The use of asphalt in the mixture will determine the stability value of the mixture. With the addition of bitumen, the value of stability will increase to the maximum limit. The addition of asphalt above the maximum limit will cause a decrease in the stability of the mixture so that the pavement layer becomes stiff and brittle. The stability value affects the flexibility of the resulting pavement layers. Research conducted [20] states that coal fly ash filler can withstand the effects of temperature in the field, by making the pavement more rigid, so that the pavement becomes more resistant to deformation. This can be seen from the stability value on the test object of 1,326 kg. The highest stability value on the research test object was 949.31 kg at 4% HDPE content. All test specimens still meet the requirements set by the Australian Asphalt Pavement Association (AAPA) 2004, namely the stability value for porous asphalt mixtures > 500 kg.

The lowest flow value on the research test object was 1.52 mm then the flow value continued to decrease as the HDPE content increased until it reached 8% with a value of 2.30 mm. Research specimens that still meet the requirements set by the Australian Asphalt Pavement Association (AAPA) 2004 at HDPE levels of 0%, 2% and 8%. This is because the porous asphalt mixture is influenced by the viscosity of the asphalt, the addition of gradations, temperature and the amount of compaction used in addition to the asphalt content. However, mixtures that have a low fatigue number with high stability tend to be stiff and brittle. Meanwhile, mixtures that have high fatigue rates and low stability tend to be plastic and easily deform when subjected to traffic loads. Good mix density, sufficient asphalt and good stability will affect the flow value. It can be concluded that porous asphalt with bitumen content has a flow value above the minimum value of 2.00 mm which indicates that the mixture is plastic but also remains elastic in order to meet the ability of the road pavement to accept traffic loads evenly.

The marshall quotient value in the tests carried out continues to increase as the HDPE content increases. This is inversely proportional to the research [21], the test conducted stated that the Marshall quotient value continued to decrease with increasing levels of concrete waste. The highest

Marshall quotient that meets the requirements is 139.13 kg/mm. The highest Marshall quotient that meets the requirements is 667.52 kg/mm. All test specimens still meet the requirements set by the Australian Asphalt Pavement Association (AAPA) 2004, namely the marshall quotient value for a minimum porous asphalt mixture of 250 kg/mm.

Determination of the optimum HDPE content is determined from the relationship of several parameters of the porous asphalt test with the required standards. From Figure 5 it shows that at HDPE levels of 0%, 2%, 4%, 6% and 8% some test objects meet the specifications specified by the Australian Asphalt Pavement Association (AAPA) 2004. From taking the median value that meets these specifications, it can be It was concluded that the porous asphalt mixture met Marshall characteristics and had an HDPE content of 2%.

CL testing produces a value of 0.19% - 0.25%, this indicates that the test is still within the threshold, namely a maximum of 0.3%. Meanwhile, the AFD test has a value of 6.21% – 6.90%, this states that the test still meets the requirements because the maximum test limit is 35%.

4. CONCLUSION

The results of the marshall characteristic test on optimum asphalt content (KAO) for porous asphalt mixtures. From the results obtained the highest VIM value was obtained at 6% with a value of 23.45% and the lowest was obtained at 4% with a value of 18.99% and for the highest VMA value obtained at 6% content of 23.52% and for the lowest value obtained at 4% content is 19.04%, while for the highest Stability value can be obtained at 6% content of 650 kg and for the lowest value obtained at 4.5% content it has a value of 563 kg and for the Flow value obtained the highest is at a content of 4% by 5 mm and for the lowest value at a content of 6% by 4 mm while for the value obtained from the highest MQ at a content of 4% by 255 kg/mm and for the lowest value which is found at a content of 5.5% by 155 kg /mm.

The results of the marshall characteristic test on a porous asphalt mixture with HDPE plastic additives stated that the highest VIM value was obtained at 2% content to obtain a value of 18.18% and the lowest at 8% content to obtain a value of 6.79% and for the VMA value which was the highest value was obtained at 8% content of 36.90% and the lowest value was obtained at 2% content of 29.40%. Whereas the highest Stability value can be obtained at 4% content of 949.31 kg and for the lowest value obtained at 2% content it has a value of 640 kg and for the Flow value obtained the highest is at 2% and 8% content of 2.30 mm and for the value the lowest is at 6% content of 1.52 mm while for the value obtained from the highest MQ at 4% content is 667.52 kg/mm and for the lowest value is found at 2% content of 284.63 kg/mm.

REFERENCES

[1] S. Aripin, B. Saing, and E. Kustiyah, “Studi pembuatan bahan alternatif plastik biodegradable dari pati ubi jalar dengan plasticizer gliserol dengan metode melt intercalation,” *J. Tek. Mesin Mercu Buana*, vol. 6, no. 2, pp. 79–84, 2017, doi: http://dx.doi.org/10.22441/jtm.v6i2.1185.

[2] A. D. Widodo, M. A. Jihan, A. Nugroho, T. Mugiono, A. H. B. Kuncoro, and S. Hardwiyono, “Pengaruh Penambahan Limbah Botol Plastik Polypthylene Terepthalate (PET) Dalam Campuran LASTON-WC Terhadap Parameter Marshall,” pp. 1–12, 2015.

[3] J. R. Jambeck *et al.*, “Plastic waste inputs from land into the ocean,” *Science (80-.).*, vol. 347, no. 6223, pp. 768–771, 2015, doi: 10.1126/science.1260352.

[4] A. M. Díez-Pascual and A. L. Díez-Vicente, “Poly(3-hydroxybutyrate)/ZnO bionanocomposites with improved mechanical, barrier and antibacterial properties,” *Int. J. Mol. Sci.*, vol. 15, no. 6, pp. 10950–10973, 2014, doi: 10.3390/ijms150610950.

[5] Supriyanto, S. W. Mudjanarko, Koespiadi, and A. D. Limantara, “Studi penggunaan variasi campuran material plastik jenis high density polyethylene (Hdpe) ada campuran beraspal

untuk lapis Aus Ac- Wc (Asphalt Concrete Wearing Course)," *Paduraksa*, vol. 8, no. 2, pp. 222–233, 2019.
[6] A. Masyruroh and I. Rahmawati, "Pembuatan Recycle Plastik Hdpe Sederhana Menjadi Asbak," *ABDIKARYA J. Pengabdi. dan Pemberdaya. Masy.*, vol. 3, no. 1, pp. 53–63, 2021, doi: 10.47080/abdikarya.v3i1.1278.
[7] B. Oktaviastuti, H. S. Wijaya, and P. Indrawan, "Pengaruh Penambahan Serbuk Ban Bekas Untuk Bahan Tambah Campuran ATB (Asphalt Treated Base)," *Reka Buana J. Ilm. Tek. Sipil dan Tek. Kim.*, vol. 3, no. 1, pp. 16–29, 2018.
[8] B. Oktaviastuti and Y. Yurnalisdel, "Studi Kuat Tekan Beton Geopolymer Dengan Fly Ash Sebagai Perkerasan Kaku Di Pesisir Pantai," *Fondasi J. Tek. Sipil*, vol. 9, no. 2, pp. 201–214, 2020.
[9] B. Oktaviastuti, A. Leliana, and L. Abid, "Pengaruh Bahan Tambah Serbuk Ban Bekas Pada Konstruksi Hotrolled Sheet-Wearing Course," no. 2008, pp. 4–9, 2020.
[10] Blima Oktaviastuti, Galih Damar Pandulu, and Evy Lusyana, "Kuat Tekan Beton Geopolymer Berbahan Dasar Abu Terbang (Fly Ash) Sebagai Alternatif Perkerasan Kaku di Daerah Pesisir," *Reka Buana J. Ilm. Tek. Sipil dan Tek. Kim.*, vol. 6, no. 1, pp. 78–87, 2021.
[11] L. Arlia, S. M. Saleh, and R. Anggraini, "Karakteristik Campuran Aspal Porus Dengan Substitusi Gondorukem Pada Aspal Penetrasi 60/70," *J. Tek. Sipil*, vol. 1, no. 3, pp. 657–666, 2018, doi: 10.24815/jts.v1i3.10011.
[12] T. Rizkianto, A. Setyawan, and D. Sarwono, "Pengaruh Pengisian Rongga Pada Campuran Aspal Porus Menggunakan Aspal Polimer Starbit E-55 Terhadap Kuat Tekan Dan Kuat Tarik," pp. 479–484, 2015.
[13] D. Andreas Lubis, Y. Fitrianingsih, S. Pramadita, and G. Christiadora Asbanu, "Pengolahan Sampah Plastik HDPE (High Density Polyethylene) dan PET (Polyethylene Terephtalate) Sebagai Bahan Bakar Alternatif dengan Proses Pirolisis," vol. 20, no. 4, pp. 735–742, 2022, doi: 10.14710/jil.20.4.735-742.
[14] R. A. Laksono, "Pengaruh Penambahan Slag Sebagai Bahan Substitusi Agregat Halus Terhadap Karakteristik Marshall Dan Permeabilitas Pada Campuran Panas (Hot Mix) Aspal Porus," *J. Rekayasa Tek. Sipil Univ. Negeri Surabaya*, vol. 1, no. 1, pp. 56–64, 2017.
[15] I. R. D. Supriyadi, B. Rahardjo, and Pranoto, "Kajian eksperimental campuran aspal porus den- gan bahan tambahan plastik hdpe (high density poly ethylene)," *J. Sipil Statik*, vol. 23, no. 2, pp. 19–28, 2018.
[16] N. Luh, S. Eka, A. N. Tajudin, and J. Pratama, "Menggunakan Agregat Terselimut Limbah Plastik Ldpe (Low Density Polyethylene)," *J. Muara Sains, Teknol. Kedokt. dan ilmu Kesehat.*, vol. 3, no. 1, pp. 123–136, 2019.
[17] Australian Asphalt Pavement Association (AAPA), "Open Graded Asphalt - Implementation Design Guide," no. 1, p. 40, 2004.
[18] S. Hadi, *Metodelogi Research*. 1987.
[19] M. Sa'dillah and A. Leliana, "Karakteristik Aspal Beton Lapis Aus (AC-WC) Dengan Penambahan Bahan Pengisi Abu Terbang Batubara," *Pros. SENTIKUIN (Seminar Nas. Teknol. Ind. Lingkung. dan Infrastruktur)*, vol. 3, pp. 1–8, 2020.
[20] M. Z. Arifin, "Pengaruh Penggunaan Abu Terbang Batubara Sebagai Bahan Pengisi Terhadap Modulus Resilien Beton Aspal Lapis Aus," *J. Himpun. Pengembang Jalan Indones.*, vol. 4, no. 1, pp. 59–66, 2018, doi: https://doi.org/10.26593/jh.v4i1.2849.%25p.
[21] M. Sa'dillah, Y. E. Fajarwati, and R. A. Primasworo, "Kinerja Campuran Aspal Porus Dengan Subtitusi Limbah Beton Sebagai Bahan Ramah Lingkungan," *J. Tek. Sipil*, vol. 25, no. 1, 2021, [Online]. Available: https://ojs.unud.ac.id/index.php/jits/article/view/77684