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Improve the Marshall Stability of Porous Asphalt Pavement with HDPE Addition

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Abstract. Porous asphalt pavement is defined as an asphalt concrete with air voids content of around 20% and capable of forming drainage channels inside the mixture. It consists of an open-graded asphalt mixture composed predominantly of embedded-occluded single-sized macadam from interlocking processes. Porous asphalt is reported to have high shear resistance and dry quickly, conversely, it has low stability, costly maintenance and low service life. Although there are some disadvantages in the use of porous asphalt, it is still a good choice in area that experience heavy annual rainfall. High Density Polyethylene (HDPE) plastics is harder, opaque, stronger, and resistant to high temperatures that has a tensile strength of 3100-5500 psi. This study aims to investigate the effect of HDPE as an additive to produce HDPE Asphalt Binder (HAB) on porous asphalt pavement. Marshall parameters was determined based on AAPA 2004 standard. As a result, 4% HDPE achieved a maximum stability value of 870 kg at the optimum asphalt content 5.54%. Stability value with HDPE addition increased by 61.1% of porous asphalt pavement without HDPE addition. Thus, the use of HDPE for Asphalt Binder as an additive was able to increase the binding strength of the asphalt and the disadvantages are expected to be minimized.

Keywords: *Porous Asphalt; High Density Polyethylene; Marshall Stability*

1 Introduction

The type of asphalt mixture is generally determined by the aggregate gradation, asphalt, and the mixing or compacting temperature. A typical porous asphalt has an open graded surface that has been developed in some developed countries and is only intended for wearing surface only [1].

Porous asphalt is a pavement where the water allows to enter through the foundation structure of the pavement and flowed to the edge then continued to the original soil [2]. Porous asphalt mixture generally has a low stability value which is highly dependent on the quality of binder, since the strength of the porous asphalt depends on the binding properties to bind aggregate.

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Asphalt as a binder in flexible pavement can be modified with addition of material which aims to improve the physical properties of asphalt such as viscosity, penetration, and softening point (Directorate General of Highways, 2004) [3]. Some alternatives of making modified asphalt is by utilize of other materials as an additive which is supposed to improve the quality of asphalt, for instance, elastomeric polymer, rubber, or plastics such or any other waste material, where these material is almost like asphalt, were melted through any heating processes [4].

The use of waste materials as an additive in asphalt mixtures will indirectly reduce the amount of waste disposal, especially the plastics waste is difficult to decompose. Plastic has hydrophobic and thermoplastic properties this trait is similar to the nature of the asphalt which makes it something potent as an additive as well as a synthetic polymer made of petroleum (non-renewable) that cannot be degraded by microorganisms in the environment.

Therefore, making the plastic as an additive in asphalt mixture is a good alternative to preserve the environment. Especially for asphalt porous mixture that need more durable binder for its service life.

2 Literature Review

2.1 Porous Asphalt

Porous asphalt is an asphalt mixture, where its porosity is higher than the other pavement types. The porosity of asphalt resulted in using the less amount of smaller proportion of fine aggregates. The larger pore or void content is expected to produce a rougher surface so that it can increase the skid resistance of the pavement [4].

The porous asphalt uses 85% of course aggregate to the total weight of the mixture, that resulted in open and hollow structure. The existing of porosity is expected to increase the ability to drain water either vertically or horizontally.

Specification of porous asphalt aggregate requirements and the provision of porous asphalt mixture based on Australian Asphalt Pavement Association (AAPA) can be seen in tables 1 as follows:

Table 1: Porous Asphalt Specification based on AAPA standard

No	Criteria	2004	1997
1	Cantabro loss (%)	Maks 35	Maks 20
2	Run Flow test (%)	maks 0.3	Maks 0.3
3	Void in Mineral Aggregate (%)	18-25	10-25.
4	Marshall Stability (kg)	min 500	Min 500
5	Marshall Flow (mm)	2-6.	2-6.
6	Marshall Quotient (kg/mm)	maks 400	Maks 400
7	Number of Blows	50	-

Porous asphalt is the gap graded pavement which is mainly rely on binder quality to bind the aggregate in order to produce the high stability and long service life pavement. The porous asphalt pavement has a dual drainage system that is, the water flows through the surface and flows out to the side of the road. Secondly, the pores of the mixture allow water to seep into the layer and flow to the edge of the road. This dual water drainage process requires the support of an impermeable layer below the porous asphalt layer so that water does not seep into the road foundation layer [4].

2.2 High Density Polyethylene (HDPE)

HDPE or high density polyethylene is one type of plastic that can be found as a bottle of liquid soap, lotion, shampoo and floor cleaning fluid. HDPE plastic is strong, hard, opaque and resistance to high temperatures. HDPE is one type of plastic thermoplast that has a melting point (200-280ºC) and made from petroleum.
A Plastic can be classified as thermoplast and thermoset. Thermoplast plastic is plastic that can be recycled, while thermoset, it cannot be recycled [5].

The tensile strength of HDPE is quite high at 3100 – 5500 psi [6]. Tensile strength is the ability of a material to withstand a pulling (tensile) force. As a comparison, the tensile strength for a metal rod one square inch in cross section can withstand a pulling force of 1,000 pounds but breaks if more force is applied, the metal has a tensile strength of 1,000 pounds per square inch.

Kofteci was investigated the effect of HDPE based plastic waste for Hot Mix Asphalt (HMA) pavement. It was added to the asphalt as modifier in to amount of 1%, 2%, 3%, 4% then tested for Marshall test and Indirect Tensile Test (ITT) method [7]. Then, the results showed that the 4% has achieved the best performance in term of Marshall Stability.

Naskar et.al, was conducted the studies on waste plastic to produce modified bituminous binders where using different plastic contents (0 to 7% by weight of asphalt). It was concluded that 5% plastic content expected to yield optimal performance [8].

Hence, the probability of HDPE for asphalt mixture additives become more interesting to investigate, especially, for porous asphalt mixture where the strength is mainly relying on the binder performance to stick the aggregates together. In doing so, it is expected to increase the durability, stability of pavement layers which is resistance to the water bad effect on pavement as well as to the weather changes. Furthermore, the addition of HDPE plastic waste as binder or pavement addition can reduce the pollution caused by the amount of plastic wastes.

The technology of plastic pavement has been implemented in Indonesia. Plastic road construction has been successfully completed in West Java, which is 3.5 metric tons of plastic waste material mixed with asphalt to create a 1.8 kilometre long road, covering an area of 9,781 square meters (m^2) and resulted in more durable and stronger pavement than that without plastic waste [9].

In this study, HDPE plastic waste was mixed with asphalt to form a binder for porous asphalt mixture has been investigated to determine its suitability as an asphalt additive material to enhance the pavement performance.

Thus, the purpose of this study is to evaluate the feasibility of the use of HDPE plastic as an asphalt modification, HDPE Asphalt Modification for asphalt porous pavement constructions.

3 Material and Methodology

Sample used for Marshall testing were prepared according to General Specification 2010 Division 6 Revision 3 of Indonesian Standard. The asphalt used in this study was 60/70 penetration and aggregate was prepared following Asphalt Porous specification as shown in Table 1. The experiments were start with develop the optimum asphalt content for Porous Asphalt mixture. The optimum asphalt content of control asphalt mixture was determined from asphalt content ranges from 4.5 to 6.5% of weight of asphalt mixture.

For HDPE usage investigation, the optimum asphalt content achieved previously, it was added with HDPE by a variation of 0%, 2%, 4%, 6%, 8% to asphalt weight to produce HDPE plastic Asphalt Binder.

Continuously, the aggregate with Porous Asphalt specification and HDPE plastic asphalt were prepared about ± 1200gram so as produce the height of the test sample approximately 63.5 mm ± 1.27 mm. Cylindrical samples mold of 50 mm diameter and 100 mm height were used to produce the sample using a Marshall hammer test for 75 blows on each face following the SNI 06 – 2484–1991 and AASHTO. T 245–97 [10-11].

The samples were subjected to Marshall test to evaluate stability modified asphalt with HDPE. Meanwhile, flow, Void in Mixed, Void in Mineral Aggregate and Void filled by asphalt to determine the optimum HDPE plastic as a binder. Marshall test is a common testing method in Laboratory to determine the ability of pavement layers to withstand the traffic loads without any permanent deformation as a mixture.

The test procedure in this study was based on SNI (Indonesian National Standard) and General Specification 2010 Division 6 Revision 3 [3]. Results of all the Marshall Tests were presented from Fig. 2 to Figure 6 for Stability, Flow, Void in Mixture, Void in Mineral Aggregate, Void filled with Asphalt as well as Marshall Quotient.

4 Results and Discussions

4.1 Aggregate and Asphalt

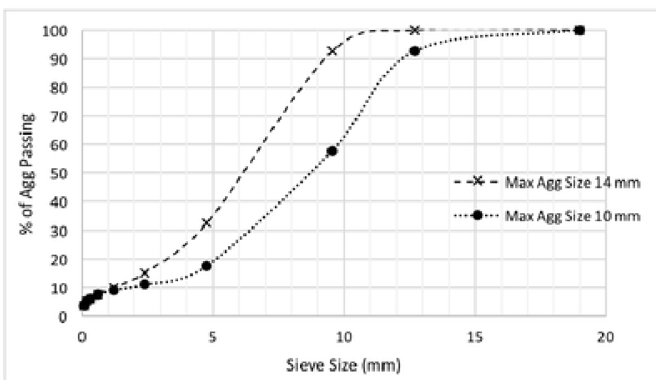

Fig. 1. Aggregate Specification of Porous Asphalt Pavement

In this study the size of the aggregate maximal is 14 mm. Then for standard percentage aggregate passes and standard asphalt level is used in accordance with aggregate standard up to 14 mm, as shown on Fig. 1, th[illegible] the rheological changes due to the addition of HDPE to asphalt has been investigated and presented in Table 2.

Table 2: The Properties of Asphalt Pen 60-70

No	Properties	Plastic Content					Unit	Standard	Value of Standard
		0%	2%	4%	6%	8%			
1	**Ductility**	100	100	100	73	70	cm	SNI 06-2432-1991	≥100
	Ductility (T-FOT)	68.5	100	100	85	80	cm	ASTM D 1754	≥50
2	**Penetration**	66.5	59.5	52.9	43.1	40.8	-	SNI 06-2456-1991	60-70
	Penetration (T-FOT)	54.2	75.2	69.9	65.1	58.4	-	ASTM D 1754	≥54
3	**Specific Gravity**	1.0452	1.0377	1.0335	1.0330	1.0413	-	SNI 06-2441-1991	≥1.00

4	**Flash Point**	273	270	288	290	286	°C	SNI 06-2433-1991	≥232
5	**Burning Point**	354	317	301	310	315	°C	SNI 06-2433-1991	≥232
6	**Softening Point**	55.5	72	84.5	97	95.5	°C	SNI 06-2434-1991	≥48
7	**Average Loss Weight**	0.031	0.010	0.070	0.081	0.15	%	SNI 06-2440-1991	≤0.8

*T-FOT = the asphalt was aged in the TFOT device for 5 hours at 163°C.

The TFOT (Thin Film Oven Test) was performed in order to identify the aging process in certain short time that might be occurred during storage, moving to the plant and mixing it, then transportation, spreading and compaction. Table 2 shows the properties of asphalt with various HDPE addition.

As can be seen from the table 2, the most of the test results were fulfil the requirement from specification. It can be stated that the addition of the HDPE into asphalt did not change the rheology behaviour of the asphalt as binder of the pavement mixture. Especially, the ductility, penetration and softening point tests, which were the main asphalt test. Ductility properties of the binder was needed to see the ability of adherence of aggregate and asphalt to hold the aggregate in place. Similarly, penetration test, the binder shows the variation of the result of aging process test was similar with penetration without aging process as well as the other test result in Table 2. The ductility without aging process with plastic content of 6% and 8% was still in the limit of specification at the value of 80-85 cm even though high percentage of plastics were being added.

4.2 Optimum Asphalt Content Determination

After determination of the proportion of aggregate and asphalt for asphalt porous mixture, samples were then prepared. A total of fifteen samples to determine the optimum asphalt content were tested by Marshall test. This stage has been carried out with asphalt content variations 4.5%, 5%, 5.5%, 6%, 6.5% without plastic addition. The results were presented in Table 3.

Table 3: Marshall Test Results of Porous Asphalt without HDPE

Criteria	Asphalt Content without HDPE				
	4.5%	5.0%	5.5%	6.0%	6.5%
Stability (kg)	617.06	427.06	563.84	495.60	579.74
Flow (mm)	3.04	3.21	4.45	3.85	4.27
Void in Mineral Aggregate (%)	23.03	24.10	22.49	23.96	25.91
Void in Mixture (%)	16.37	16.50	13.65	14.23	15.38
Void Filled with Asphalt	28.97	31.57	39.43	40.94	40.86
Marshall Quotient	204.22	132.87	130.15	135.92	137.54

As can be seen from Table 3, there were results from Marshall Test of Porous Asphalt in laboratory to determine the optimum asphalt content. Then, it can be concluded that optimum asphalt content from porous asphalt was 5.54% based on the mean value of Marshall parameter that fulfil the criteria.

Moreover, the 5.54% optimum asphalt content was being used to determine the optimum HDPE content that resulted in high stability, but also the other Marshall Parameter were fulfil the requirement from the Specification were followed.

4.3 Marshall Properties

4.3.1 Stability

The value of Marshall Stability is intended to see the changing in Stability value of the mixture for various value of plastics (HDPE) content in asphalt.

Fig.2 shows the result of stability as a function of varying the plastic content. The stability increases as the plastic content increases to the point of maximum and decreases after exceeding its maximum point even though the plastic content increases. It is observed that the stability increases as the plastics content increases from 0% to 4%, and then decreases as the plastic content increases. The maximum stability of the mixture may be due to the fact that at 4% plastic the binder penetration is lower but the ductility is still more than 100 cm. Thus, on the contrary, the decreasing of the stability may be due to the penetration of the binder continuing to decrease as well as the decreasing of the value of the ductility (as shown on table 2). Fortunately, the stability value for all the samples meet the standard required in AAPA 2004 (>500 kg).

4.3.2 Flow

Marshall Flow was measured on the samples at the same time as the Marshall Stability that measured the vertical deformation occur at the samples while being loaded. The flow value for the porous asphalt with HDPE plastics addition were presented in Fig. 3.

In this Figure, shows that the results of the flow for varying plastic content. The flow value of 0% plastic content was 5.04 mm value. An increasing of the plastics material in the binder resulted in increasing the flow up to an optimum value of binder content then the flow decreases as the plastic continue to increases. It might be due to the penetration of the binder decreases as the HDPE increases, it resulted in the harder the binder.

The samples with 2% plastic content yields the highest average value of flow i.e. 6.51 mm, while the 0% and 8% were the lowest. Additional of plastics contents higher than an optimum value starts increasing the flow value. Moreover, the range of 2-8% plastic content the value of flow is in the standard there is only some data between the range does not meet the standards specified by AAPA 2004.

4.3.3 Void in Mixture (VIM)

VIM shows the percentage of void in the mix. VIM value affects the durability of the aggregate asphalt mixture, the higher the value indicates the greater the void in the mixture. As shown in Fig.4, the highest average VIM value is at 6% plastic content with value of 16.30% and the lowest average VIM value is at 4% plastic content with value 15.09%.

The VIM value is not much different although the plastic content is varied, it is in accordance with the principle of the material used that the voids in the mixture will remain the same when the plastic content is varied because it has the same total weight of the mixture.

4.3.4 Void in Mineral Aggregate (VMA)

Void in Mineral Aggregate should not be influence or changed by changing asphalt binder content. As shown on Figure 5, the void between aggregates is not much different for various plastic content, where the average value of the VMA was 24.95% at 6% plastic content. Additionally, the lowest VMA value was 23.85% at 4% plastic content. This is suitable with the material characteristics that the voids will remain the same for different plastic content, since it has the same total weight of the mixture.

4.3.5 Void Filled with Asphalt (VFA)

From the research, the average value of VFA is 36.76% is found at 4% plastic content and the lowest VFA value is 34.69% on average at 6% plastic content, as shown in Fig.6. On the graph can be seen that the void filled with asphalt is not much different value between one with another although different plastic content. This is in accordance with the principle of the material that is VFA will remain the same when the plastic content is varied, because it has the same total weight of the mixture

4.3.6 Marshall Quotient (MQ)

By means of the stability and flow test, the Marshall Quotient can be calculated. It represents the ratio of load (stability) to deformation (flow), and it can be as an indication of the mixture's stiffness. The higher the ratio the stiffer the mixture is.

Fig. 7, shows a graph of the relationship between the plastic content and the MQ. The average value of the highest MQ was found in the mixture of 4% plastic content at 152.06 kg/mm while the lowest MQ was at the 0% plastic content that there was no plastic in the mixture at 112.31 kg/mm.

Thus, it can be concluded that the addition of 4% HDPE was the effective use to get the highest Marshall Quotient with the lowest flow and the highest the stability. However, it should also be noted that too high MQ, it raises the potential cracking of the mixture due to the higher the stiffness of the mixture due to the flexibility of the asphalt or mixture is reduced. Fortunately, all the MQ values of the samples in this study meets the standards of AAPA, 2004 which are under 400 kg/mm.

Table 4: Marshall Test Results of Porous Asphalt with HDPE Plastic

Criteria	HDPE Plastic Content				
	0%	2%	4%	6%	8%
Stability (kg)	540	800	870	788	600
Flow (mm)	5.04	6.51	5.76	5.62	5.55
Void in Mineral Aggregate (%)	24.51	24.43	23.85	24.95	24.19
Void in Mixture (%)	15.82	15.65	14.96	16.17	15.42
Void Filled with Asphalt	35.51	36.03	37.29	35.21	36.28
Marshall Quotient	112.31	142.77	152.06	118.77	134.24

Based on Marshall parameters results as shown on Table 4, the percentage of plastic content that achieved the maximum stability, lower flow value, the value of MQ as well as the void in mixture, it was found that the value of the optimum plastic content added in 5.54% asphalt content was 4%. Stability value with HDPE addition was improved by 61.1% of porous asphalt pavement without HDPE addition. Thus, the use of HDPE for Asphalt Binder as an additive was able to increase the binding strength of the asphalt and the disadvantages are expected to be minimized.

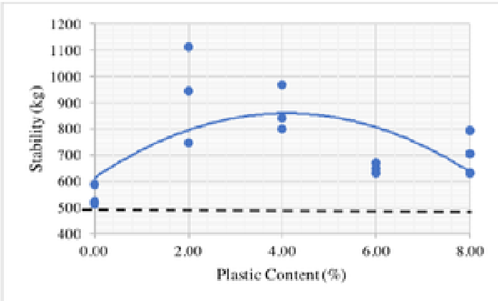

Fig.2 Stability (kg) vs. Plastic Content (%)

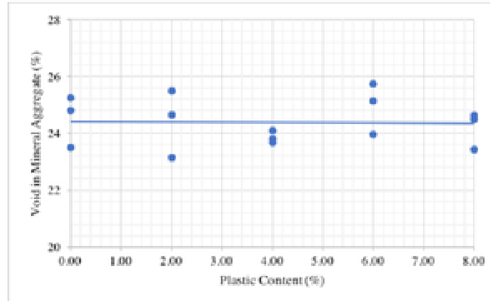

Fig.5 VMA (%) vs. Plastic Content (%)

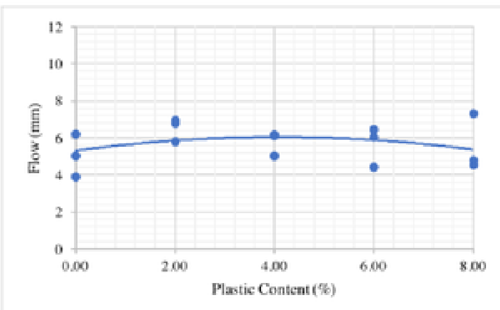

Fig.3 Flow (mm) vs. Plastic Content (%)

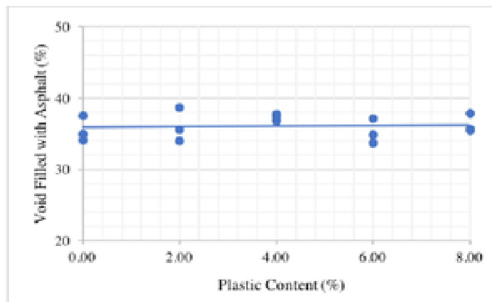

Fig.6 VFA (%) vs. Plastic Content (%)

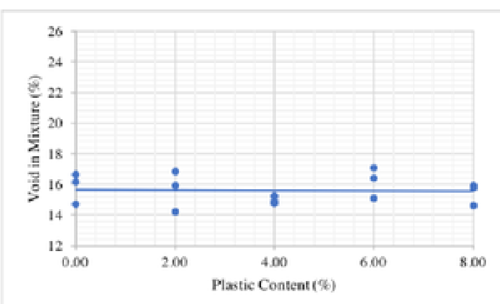

Fig.4 VIM (%) vs. Plastic Content (%)

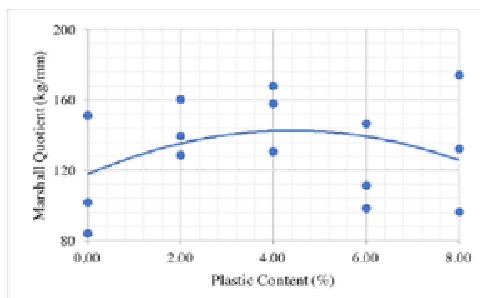

Fig.7 MQ (kg/mm) vs. Plastic Content (%)

5 Conclusions

Based on the findings of this study, the following conclusions are drawn:

1. Adding HDPE plastic to asphalt has caused a considerably increase in ductility of the binder, especially the ductility after thin film oven test (T-FOT). As well as the penetration test, HDPE binder has a better penetration value for 2% and 4% where the penetration is lower but the Ductility were still high.

2. The value of flash point and the softening point are increases with the increasing HDPE content. It indicates that the binder is less susceptible with the temperature changes. Meanwhile the Burning Point is not affected by the HDPE content in the asphalt.

3. The optimum asphalt content for Porous Asphalt was achieved at 5.54% which then HDPE was added at various percentage.

4. The stability values of the porous asphalt were found to be increasing with the increase in the amount of HDPE up to 4%HDPE plastic in the asphalt (optimum limit). After that, the stability values were decreasing.

4. Mixes with high content of HDPE (6% and 8%) showed a decrease in stability, higher flow but for the VIM, VMA and VFA are not affected by the variation of the HDPE.

5. The MQ value of the sample in this study meets the standards as it is in accordance with the 2004 AAPA standard under 400 kg / mm.

6. The optimum plastics content for Porous Asphalt Pavement achieved in this investigation was 4% at 5.54% asphalt content and the stability was improving by 61.1%.

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