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THE EFFECT OF USING POLYETHYLENE TEREPHTHALATE (PET) POLYMER ON THE MARSHALL TESTING CHARACTERISTICS OF ASPHALT MIXTURE (AC-WC)

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ABSTRACT

The increase in road traffic recently, coupled with the lack of sufficient funds for the maintenance of road pavements, can accelerate the rate of road damage. To reduce the damage, actions are needed, among others, by increasing road maintenance, improving road pavement design, and improving road pavement quality. The purpose of this study is to determine the characteristics of marshalls. This study used Polyethylene Terephthalate (PET) as an additive in AC-WC asphalt concrete. This research was carried out by adding pieces of plastic bottles that were cut with a size of ±2mm so that it was easy and fast when melting. This test is done by dry (dry process). Before adding PET, make a test object from the middle boundary gradation. Then, PET was added to the aggregate mixture, namely 1%, 3%, 5%, and 7% by weight of asphalt. The results showed that the best marshall characteristics were the addition of 3% Polyethylene Terephthalate (PET), with a stability value of 1618.859 kg. However, all the percentages of PET in this study, such as VMA, VIM, VFA, Stability, Meltability (flow), and Marshall quotient (MQ) values, have met the 2018 Bina Marga specifications even though the values are unstable or fluctuate.

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Kata Kunci: AC-WC, Aspal, Polyethylene Terepthalate (PET)

INTRODUCTION

The recent increase in road traffic coupled with insufficient funds for road pavement maintenance can accelerate the road damage rate. Several actions are needed to reduce the damage process, including increasing road maintenance, improving road pavement design, and increasing road pavement quality. One way to prevent premature damage to road pavement due to loads and the influence of water is to improve the quality of asphalt as a binder of aggregates. The method often used to improve the quality of asphalt is by adding additive materials, one of which is a plastic polymer, charcoal, or modified asphalt.

Asphalt is a viscoelastic brownish-black material, so it will soften and melt when it gets sufficient heating and vice versa. This viscoelastic property makes asphalt able to envelop and hold the aggregate in place during the production process and its service life. Asphalt is made of a chain of hydrocarbons called bitumen. If the temperature drops, the asphalt will harden and bind the aggregate in place (thermoplastic properties). As a flexible pavement construction material, asphalt is a small component, generally only 4-10% by weight or 10-15% by volume, but it is a relatively expensive component (Sukirman, 2003).

PET (Polyethylene Terephthalate) is a clear, strong polymer with gas and moisture-retaining properties. PET plastic's ability to hold carbon dioxide (carbonation) makes it ideal for use as soft drink bottles (sparkling/carbonated). In addition, PET plastic is also often used as bottled drinking

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water bottles. PET (Polyethylene Terephthalate) is a type of waste that is difficult to decompose soil organic compounds, so it is one of the causes of damage to soil elements. However, plastic bottle waste is a flexible material that can be used as an alternative additive in road pavement mixtures. Modified asphalt with Polyethylene Terephthalate (PET) polymer in the form of plastic bottles is one type of asphalt formula with the addition of polymer to obtain better road pavement properties.

Waste in Indonesia reaches 64 million tons/per year, whereas plastic bottle waste reaches 1.3 tons/per year. Based on this, the researchers tried to see the potential of plastic materials, especially Polyethylene Terephthalate (PET) plastic waste, in changing the mechanical properties of asphalt. The added material used in this study was plastic waste in the form of used plastic drink bottles. This utilization is intended to reduce the existence of plastic bottle waste so that it will not cause a negative impact but can positively impact society and the environment. The Marshall method's value is obtained from the marshall test, which aims to determine the characteristics of a flexible pavement. This marshall method consists of Marshall Test and Marshall Parameters: Stability, flow, MQ, VIM, VMA, and VFA.

The method used in this research is to use the dry process, which is a mixing method in which the plastic is put into the aggregate, which is heated at the mixture temperature. Hot asphalt is added simply by including the plastic in the hot aggregate. Plastic bottles are cut with a size of ± 2 mm so that it is easy and fast when melting. It is expected that the addition of Polyethylene Terephthalate (PET) polymer admixture can provide several advantages from the use of modified asphalt, including the pavement surface being more weather resistant, resistant to cracks due to excessive deflection, and increasing the value of stability.

LITERATURE REVIEW

PET (Polyethylene Terephthalate)

Polyethylene Terephthalate Usually, at the bottom of the plastic bottle packaging, a recycling logo is printed with the number 1 in the middle and the words PETE or PET (Polyethylene Terephthalate) under the triangle. Usually used for clear/transparent/translucent plastic bottles such as mineral water bottles, juice bottles, and almost all other beverage bottles. PET (Polyethylene Terephthalate) is a type of waste that is difficult to decompose soil organic compounds, so it is one of the causes of damage to soil elements. However, perhaps plastic bottle waste is a flexible material that can be used as an alternative additive in road pavement mixtures. (Nurminah, M, 2009), explained that Polyethylene Terephthalate is a soft, transparent, and flexible film with good impact and tear strength. With heating, it becomes soft and melts at 110°C.

Polymer Modified Asphalt

Asphalt modification is mixing asphalt with additives or additives to improve the properties of asphalt. Modified asphalt polymer is the addition of polymer as an additive to conventional asphalt to design pavements with high-temperature resistance and elasticity to reduce permanent deformation against traffic loads. The polymer often used in asphalt additives is generally plastomer (plastic). The use of asphalt polymer mixtures is a modification that is increasing not only because of economic factors but also for the sake of getting better quality and longer-lasting bitumen. Modifying asphalt polymer obtained from the interaction between asphalt components and polymer additives can improve the properties of the asphalt. In this case, the cohesiveness of the polymer additives follows the asphalt mixture.

Marshall Characteristics

Testing with the Marshall tool was carried out following Highways procedures. This test is intended to determine the mixture's characteristics and the resistance or stability to plastic melting (flow) of the asphalt mixture. The relationship between resistance (stability) and melting plasticity (flow) is directly proportional. The greater the stability, the greater the flow, and vice versa. If the flow is higher, the asphalt is more able to withstand the load. From the observations on the

Marshall test, a graph of the relationship between the percentage of asphalt content and the percentage of voids filled with asphalt (VFA) was made. Percentage of voids in the mixture (VIM), voids between aggregate grains (VMA), melting (flow), stability, and the ratio between stability and the ratio between stability and melting (MQ).

METHOD

Research on the Effect of Polyethylene Terephthalate (PET) Polymer Additive on Marshall Characteristics of Asphalt Mixture (AC-WC) was conducted at the Transportation and Remote Sensing Laboratory, Campus Brawijaya University, Malang. For the manufacture of specimens and Marshall, tests were carried out at the Transportation and Remote Sensing Laboratory of the University of Brawijaya Malang using tests based on mixed asphalt planning guidelines using the Marshall method according to the Indonesian National Standard (SNI) and the 2018 General Specifications for Road and Bridge Construction Works. Research time starts from October 25 to November 23, 2020.

The tests to be carried out include penetration testing, softening point testing, ductility, asphalt specific gravity, aggregate inspection, determination of the preferred gradation, specific gravity and absorption of coarse aggregate, flakiness and elongation index, aggregate wear testing with the Los Angeles tool, impact test, determination aggregate proportions and needs, inspection of the mixture using the marshall method, calculation of the weight percentage of polymer polyethylene terephthalate (PET).

RESULT AND DISCUSSION

Asphalt Inspection

Before manufacturing the Marshall test object, in this study, hard asphalt was tested at the Road Pavement Materials Laboratory, Civil Engineering Program, Brawijaya University, Malang. In this study, the asphalt used was 60/70 penetration asphalt. Examinations include penetration, specific gravity, ductility, and softening point. From the inspection results, the asphalt meets the demanding asphalt standard requirements based on the SNI (Indonesian National Standard) and the 2018 Bina Marga, which have been determined. The results of the examination can be seen in Table 1.

Tabel 1. Asphalt Pen Test Results 60/70 before mixing PET

Checking type	Method	Result	Spesification		Information
			Min	Max	
Penetration	SNI 06-2456-2011	61,87	60	70	Fulfill
Soft Point	SNI 06-2434-2011	49	48	58	Fulfill
Asphalt Specific Gravity	SNI 06-2441-2011	1,039	1	-	Fulfill
Ductility	SNI 06-2432-2011	150	100	-	Fulfill

Aggregate Inspection

In this study, the aggregates used for manufacturing specimens were obtained from rock crackers. The aggregates tested were coarse aggregate (CA), medium aggregate (MA), and fine aggregate (FA).

Coarse Aggregate Testing

Coarse aggregate tests include sieve analysis, aggregate water absorption, aggregate stickiness, and aggregate specific gravity examination, presented in Table 2.

Tabel 2. Coarse Aggregate Test Results

Checking type	Method	Result	Spesification	Information
Aggregate Absorption	SNI-1969-2008	2,77%	≤ 3%	Fulfill
Bulk Specific Gravity	SNI-1969-2008	2,59 gr/cc	≥2,5 gr/cc	Fulfill
Apparent Specific Gravity	SNI-1969-2008	2,79%	-	Fulfill
SSD specific gravity	SNI-1969-2008	2,66%	-	Fulfill

Fine Aggregate Testing

Fine aggregate testing consists of sieving analysis, examination of absorption specific gravity, bulk specific gravity, saturated specific gravity, and apparent specific gravity. For filler testing, a specific gravity test is carried out. The results of fine aggregate testing can be concluded in Table 3.

Tabel 3. Fine Aggregate Test Results

Checking type	Method	Result	Spesification	Information
Aggregate Absorption	SNI-1969-2008	2.43%	≤ 3%	Fulfill
Bulk Specific Gravity	SNI-1969-2008	2.62 gr/cc	≥2,5 gr/cc	Fulfill
SSD Specific Gravity	SNI-1969-2008	2.69%	-	Fulfill
Apparent Specific Gravity	SNI-1969-2008	2.80%	-	Fulfill

Aggregate Mixing

After testing the materials, coarse aggregate, fine aggregate, and stone ash aggregate, followed by aggregate proportions. To determine the process of designing and selecting suitable materials to determine the proportion of aggregate using the Job Mix Formula. The way to determine it is by trial and error. The method used to proportion aggregates is based on the ideal gradation determined based on the 2018 Bina Marga specifications. The gradation of mixed choices can be seen in Figure 1.

The results of the aggregate combination proportions obtained for each aggregate are as follows: Coarse Aggregate (CA): (100%-94%) + (94%-89%) + (89%-69%) = 31%, Fine Aggregate (FA): (69%-40%) + (40%-28%) + (28%-20%) + (20%-12%) + (12%-8%) + (8%-4%) = 65%, Filler (FF): 4% CA = Combination of cumulative passing aggregates retained in sieve No.4 FA = Combination of cumulative passing aggregates that pass sieve No.8 to sieve No.200 FF = Combination of cumulative passing aggregates that pass sieve No.200.

The cumulative retained aggregate proportions above are obtained from the results of a gradation check or sieving analysis made in a graph based on the pass percentage for each sieve number used. After obtaining the results of the proportion of each aggregate, the optimum asphalt content is calculated for the plan.

Calculation and Determination of Initial Asphalt Content

In this study, several tests and calculations were carried out. The initial stage was calculating the optimum bitumen content (Pb), after which the Marshall and immersion calculations were carried out. The Marshall test was carried out to find the optimum asphalt content (KAO) with the requirements according to specifications for the AC-WC (Asphalt Concrete-Wearing Course) mixture. The Marshall test is carried out under standard test conditions, (2x75) collisions for national roads, in addition to determining VIM, VMA, VFA, Density, stability, flow, and Marshall Quotient to determine the optimum asphalt content (KAO). When mixing with PET plastic bottles.

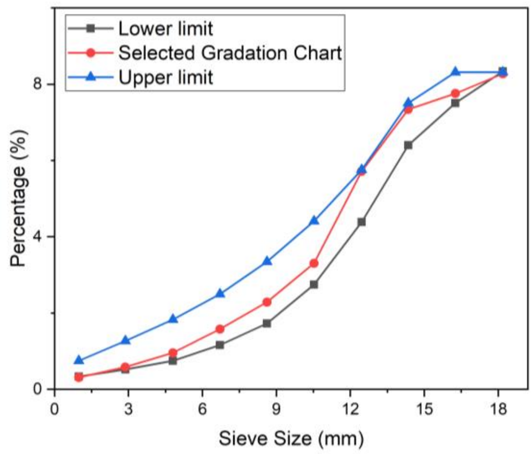

Figure 1. Selected Gradation Chart

Based on the results of these calculations, to obtain the optimum asphalt content, the asphalt content was varied as follows: 5%, 6%, 7%. Asphalt range is made with 3 grades because to determine the minimum KAO value required to use 3 asphalt grade ranges.

Tabel 4. 1 Asphalt Content For One Test Object

total agregat (gram)	range aspal (gram)		
	5%	6%	7%
1200	60	72	84

Marshall Test Results

1. Characteristics of the Mix Laston AC-WC (Asphalt Concrete-Wearing Course)

The results of the influence of the mixture characteristics obtained through the Marshall test and calculation, the next step is to graph the relationship between asphalt content with the characteristics obtained, including VMA, VFA, VIM, Stability, Flow, and Marshall Quotients and their effects are as follows:

2. Cavities Between Aggregate Granules (Void in Mineral Aggregate/VMA)

Cavities between mineral aggregates (VMA) are void spaces between aggregate particles on pavement, including air voids and effective asphalt volume (excluding asphalt volume absorbed by aggregate). A VMA that is too large causes the mixture to have low stability, while a VMA that is too small causes the mixture to have low durability.

The VMA values for the Laston AC-WC (Asphalt Concrete-Wearing Course) mixture at 5%, 6%, and 7% asphalt content, respectively, were 13.673%, 15.199%, and 16.653%. The minimum specification for the Laston AC-WC (Asphalt Concrete-Wearing Course) mixture is 15%, so the test results with 6% and 7% asphalt content have entered the specified specifications, and for 5%, asphalt content is not following specifications presented in figure 2.

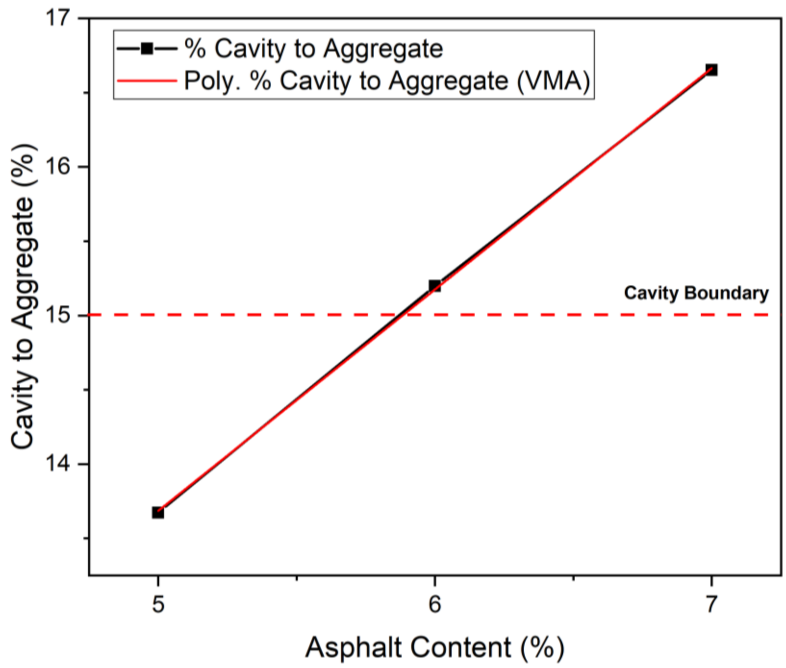

Figure 2. Graph of Relationship Between Asphalt Content and Average VMA

3. Asphalt Filled Cavities (Voids filled with asphalt/VFA)

Cavities filled with bitumen (VFA) are the percentage of cavities between aggregate particles (VMA) filled with bitumen after the compaction process does not include bitumen absorbed by the aggregate. The higher the VFA value, the more voids in the mixture filled with asphalt. The mixture's impermeability to water and air is also higher. If the VFA value is too high, it will cause bleeding, and the asphalt will lift or melt because the inner cavity is too dense.

The VFA values for this Laston AC-WC mixture at 5%, 6%, and 7% were 99.277%, 99.228%, and 99.218%. The minimum VFA value for the Laston AC-WC mix is 65%.

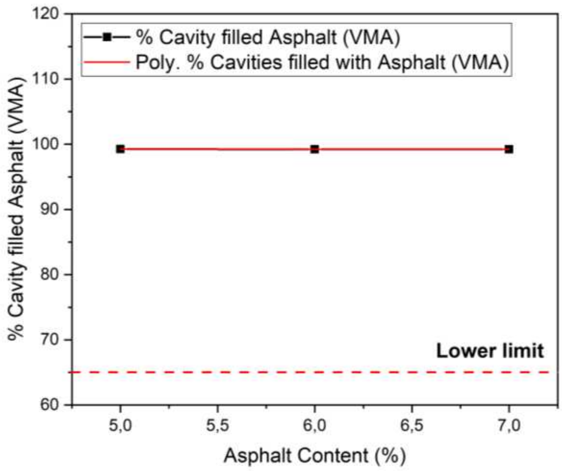

Figure 3. Graph of Relationship between Asphalt Content and Average VFA

4. Air voids in the aggregate (Void in the mix aggregate/VIM)

Void in the mix aggregate/VIM is the percentage of voids present in the mixture. VIM is used to determine the size of the voids in the asphalt mixture. The air voids in the mixture (VIM) in the asphalt pavement mixture consist of air spaces between the asphalt-covered aggregate particles. A high VIM value can cause oxidation/aging of asphalt with the entry of air so that the mixture is porous. In contrast, if the VIM value is too low, it will result in bleeding due to high temperatures, and the viscosity of the asphalt will decrease.

The VIM values for this Laston AC-WC asphalt mixture at 5%, 6%, and 7% were 3.819%, 3.524%, and 3.924% see in figure 4a. Typical specifications for VIM values are 3% and a maximum of 5%.

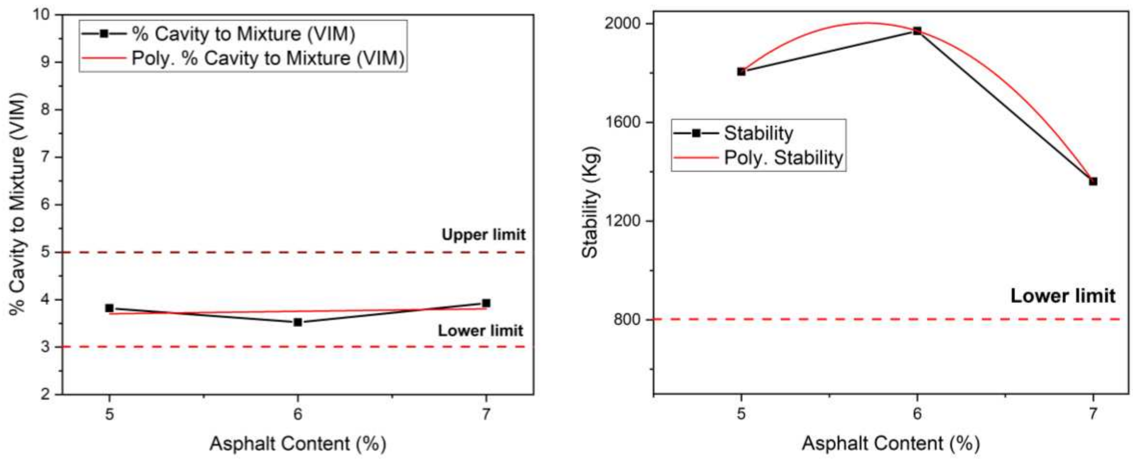

Figure 4. Graph of the Relationship between (a) Asphalt Content versus Average VIM and (b) Asphalt Content versus Average Stability

5. Stability

Stability is the ability of the pavement layer to accept traffic loads without changing shapes such as waves, grooves, or bleeding. Low stability will make it easier for deflection/waves to occur and vice versa. If the stability is too high, it can cause the mixture to become stiff and can cause cracking and breakage/cracks quickly.

Corrected stability values (kg) of this Laston AC-WC mixture at 5%, 6%, and 7% asphalt content were 1805.51kg, 1970.628kg, and 1360.415kg. The 2018 Public Works specifications show that the minimum stability value is 800 kg see in figure 4b.

6. Flow

Melt (flow) is the decrease in a mixture due to load expressed in mm units. The yield value is affected by asphalt content, asphalt gradation, viscosity, and temperature during compaction. Low melting and high stability values tend to produce an increasingly stiff mixture, resulting in easy cracking when it receives a load that is too heavy. Conversely, if the melting value is high, plastic causes deformation due to high traffic loads.

The average flow values for this Laston AC-WC mixture at 5%, 6%, and 7% asphalt content were 3.46 mm, 3.66 mm, and 3.47 mm. The general specifications for the flow value for the Laston AC-WC mixture are 2 mm and a maximum of 4 mm see in figure 5a.

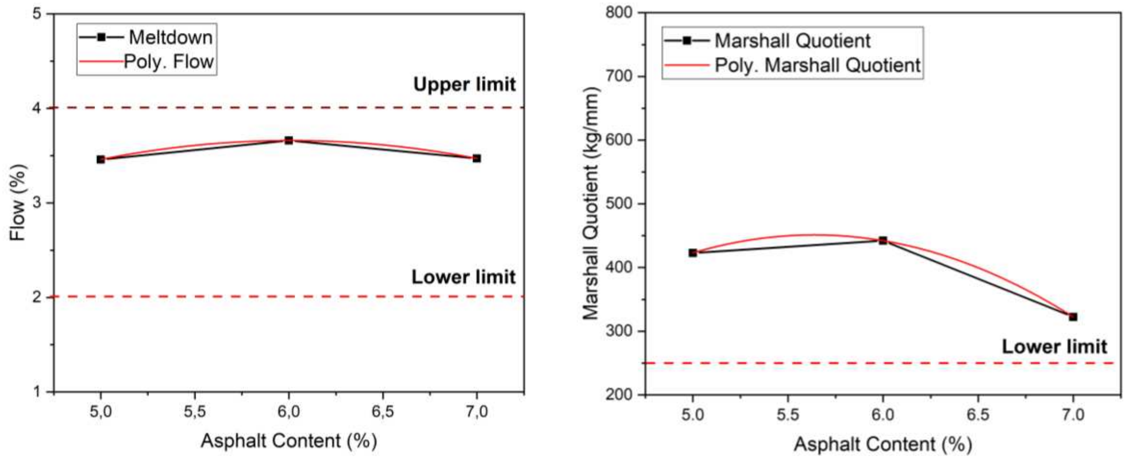

Figure 5. Graph of the Relationship between (a) Asphalt Content versus Average Flow and (b) Asphalt Content versus Average MQ

7. Marshall Quotient

Marshall Quotient is a comparison of the stability value of the mixture with the flow. The value of the marshall quotient (MQ) indicates the stiffness property of an asphalt mixture. If the MQ value is higher, it indicates the mixture tends to be stiff and easily cracks. If the MQ value is low, the mixture will be more plastic, so it is easy to change shape when receiving an excessive load. The average Marshall Quotient (MQ) value for this Laston AC-WC mixture at 5%, 6%, and 7% asphalt content was 422.964kg/mm, 442.080 kg/mm, and 322.360 kg/mm. The general specification of the MQ value is 250 kg/mm. See figure 5b.

Mixture of Laston AC-WC with PET Polymer (Polyethylene Terepthalate) Against Asphalt Mixture

From the calculation results of the table above, it can be seen that the characteristic values of the Marshall Laston AC-WC mixture using the added ingredient Polyethylene Terepthalate (PET) experienced a change in the properties of the mixture compared to the pure asphalt content. Then a graph of the relationship between the plastic bottle content and asphalt content was made namely VMA, VIM, VFA, Stability, Flow and Marshall Quotient (MQ).

1. Cavities Between Aggregate Granules (Void in Mineral Aggregate/VMA)

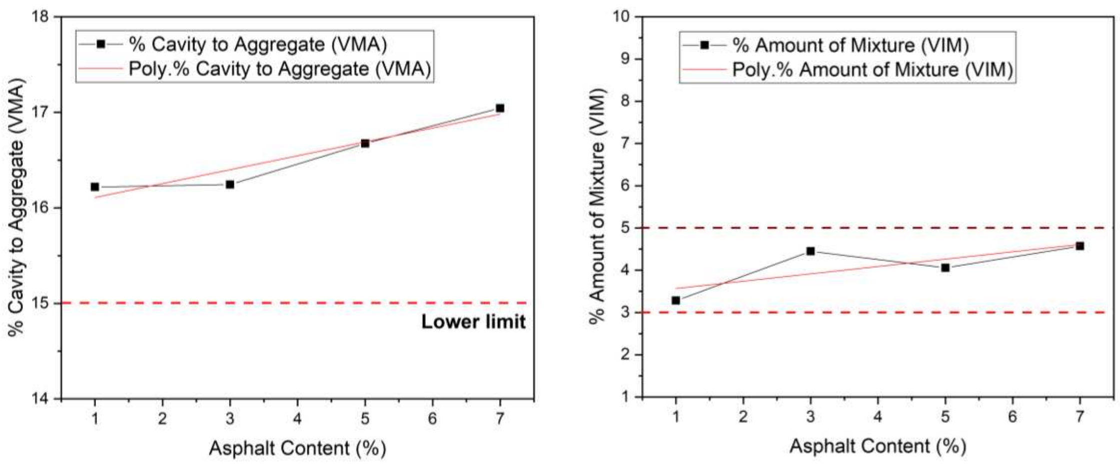

Figure 6. Graph of Relationship Between (a) VMA versus Mixed Plastic Bottles and (b) VIM versus Mixture of Plastic Bottles

Figure 6a shows an increase in the VMA value as the levels of Polyethylene Terephthalate (PET)/plastic bottles were added to the Laston AC-WC. Sequentially the VMA values were 16.218%, 16.245%, 16.675%, and 17.044% for PET content of 1%, 3%, 5%, and 7%. These values still met the requirements above the minimum limit of 15%. An increased VMA value indicates that the air voids between the aggregates are getting bigger. According to Ammar Fadhil, the VMA value increased due to the asphalt with the PET mixture covering the aggregate grains and forming a thick blanket, causing the air voids between the aggregates to increase (Fadhil, 2017). This will cause the pavement layer to be watertight, not easily oxidized, and not easily damaged (Suhardi et al., 2016). Herwin et al. also explained that the high VMA value indicated that more asphalt would be able to fill the voids between the aggregates so that the mixture would be denser (Wardana & Mahardi, 2020).

2. Air Cavities in the Mix (Voids in the Mix/VIM)

The VIM values for the Laston AC-WC mixture with Polyethylene Terephthalate (PET)/plastic bottles added at levels of 1%, 3%, 5%, and 7% are 3.282%, 4.448%, 4.058%, and 4.571%. Variations in VIM values meet the specifications of 3-5%. At 3% plastic bottle waste variations, there is an increase of 1.166% from 1% waste variations to 4.448%. At 5% content, there was a decrease of 0.39% from 3% to 4.058% see in figure 6b. Meanwhile, for the 7% waste variation, there was another increase of 0.513% from the 5% waste variation and was the highest VIM value. The VIM value in this study increased with increasing levels of PET added to the Laston AC-WC mixture.

These results are similar to the research conducted by Munadhiroh and Ismaili, who found that the VIM value increased as the PET content increased (Munadhiroh & Ismaili, 2019). The increase in the VIM value is because the asphalt, which functions as a filler for the voids between the aggregates, hardens so that there are more and more voids that are not filled (Fadhil, 2017; Iqbal et al., 2018). This is likely because the PET sticks to the aggregate, so it covers the cavities in the mixture and because of the good compaction quality (Suhardi et al., 2016). If the VIM value is too small, it can cause bleeding if the temperature increases and causes the cavity of the mixture to be filled with filler (Pratama et al., 1989).

3. Asphalt Filled Air Cavities (Voids Filled Asphalt/VFA)

The VFA values for the Laston AC-WC mixture with Polyethylene Terephthalate (PET)/plastic bottles added at levels of 1%, 3%, 5%, and 7% were 99.202%, 99.209%, 99.242%, and 99.268%. This VFA value variation meets the requirements in the 65% specification. As the asphalt and PET content increases, the VFA value increases. At the 3% content variation, there was an increase of 0.007% from the 1% content variation. Meanwhile, for the 5% variation, there was an increase of 0.033% from the 3% variation. At the 7% content variation, there was an increase of 0.026% from the 5% content variation. Graph of Relationship Between VFA versus Mixture of Plastic Bottles presented in table 7a.

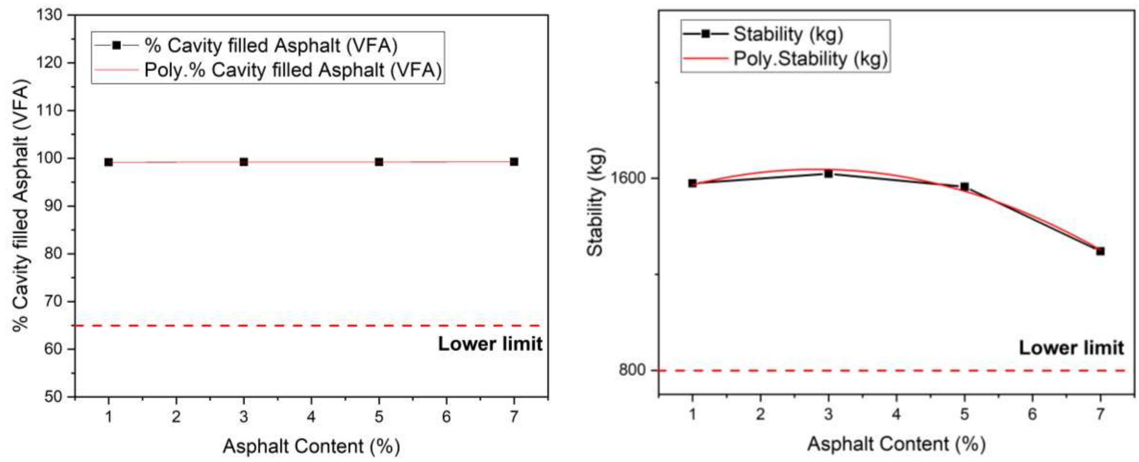

Figure 7. Graph of Relationship Between (a) VFA versus Mixture of Plastic Bottles and Stability versus Mixture of Plastic Bottles

The increase in the PVA value is due to the use of much asphalt so that the aggregate composition is reduced, where the asphalt will fill the cavities between the aggregates (Iqbal et al., 2018). This indicates that the higher the VFA value, the more voids in the mixture are filled with asphalt, so the mixture is more water and airtight (Permana & Mahardi, 2019). A VFA value that is too high will cause the asphalt to rise when the pavement temperature is high. In contrast, a smaller VFA value causes the mixture to be porous and less impermeable to water and air, so the asphalt layer is easily oxidized and causes the layer not to last long. (Razali, 2014).

4. Stability

Stability values for the Laston AC-WC mixture with Polyethylene Terephthalate (PET) added/plastic bottles with levels of 1%, 3%, 5%, and 7% were 1579.375 kg, 1618.859 kg, 1565.016 kg, and 1295.805 kg. Graph of relationship between stability versus mixture of plastic bottles presented in table 7b

The results obtained in this study indicate that the stability values obtained tend to fluctuate with increasing levels of PET added. The stability value tends to increase when adding PET with a content of 1 – 3%. The increase in stability with the addition of PET is because the asphalt-covered aggregate tends to expand, and the asphalt's adhesion to the aggregate improves so that the interlocking between grains strengthens and interlocks (Gaus et al., 2020; Iqbal et al., 2018). While the decrease in the value of stability is due to excessive asphalt mastic pushing, and new cavities appear so that the value of stability decreases. However, the decrease in the stability value is insignificant and meets the requirements according to the minimum stability value of modified asphalt, which is 800 kg. So the stability value obtained is quite good.

5. Flow

Flow values for the Laston AC-WC mixture with Polyethylene Terephthalate (PET) added/plastic bottles with levels of 1%, 3%, 5%, and 7% are 2.37 mm, 2.48 mm, 2.556 mm and 2.82 mm. The flow value is included in the flow value specification, which is 2-4 mm. Following the relevant results in Figure 8, it shows that the flow value continues to increase as the PET content increases.

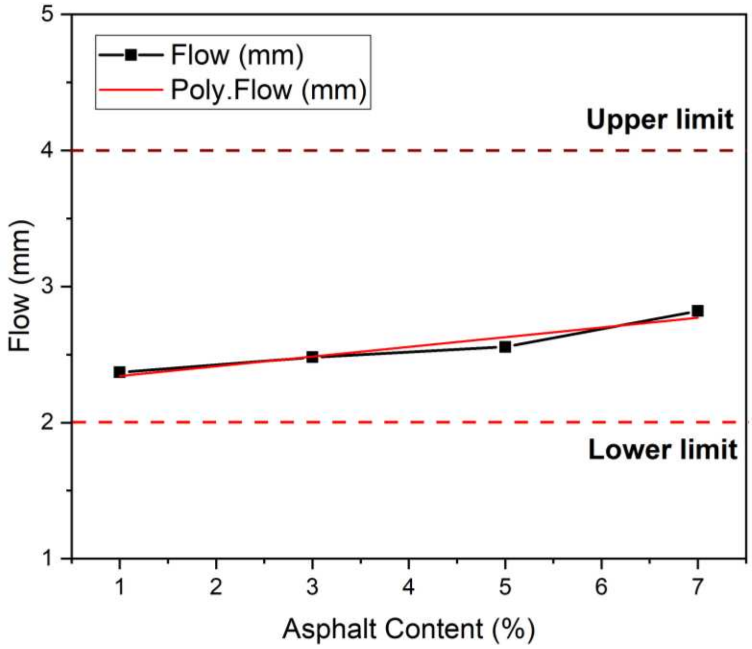

Figure 8. Graph of Relationship Between Flow and Mixture of Plastic Bottles

This indicates that adding PET will make the asphalt mixture more plastic. So asphalt with PET mixture can be confirmed to have a good deformation rate, or it can be said that it is more able to follow the deformation due to traffic loads. Similar results were also obtained from previous studies, which said that the level of flexibility of the Laston-WC mixture would increase with an increase in the added plastic content (Widodo et al., 2017). Sari Pertiwi et al. (2020) also obtained similar results. Namely, the flow value increased by adding 1.5 – 5.5% PET (Pertiwi et al., 2020).

6. Marshall Quotient (MQ)

The MQ values for the Laston AC-WC mixture with the addition of Polyethylene Terephthalate (PET) Polymer/plastic bottles with levels of 1%, 3%, 5%, and 7% are 421.076 kg/mm, 480.724 kg/mm, 525.121 kg/mm, and 539.026 kg/mm. In theory, the MQ value positively correlates with stability values and negatively with flow values (Gunadi et al., 2013). Based on the analysis results in the previous sub-chapter, an addition of 1% of PET content shows a low stability value and a high flow value, producing a lower MQ value. The low MQ value indicates that asphalt has poor properties (Fadhil, 2017). Nevertheless, along with the addition of PET, the stability value increases, which causes the MQ value also to increase. An increase in the MQ value indicates that the sample has a stiff layer. However, the MQ values for all samples were above the minimum limit for MQ values, namely 250 kg/mm.

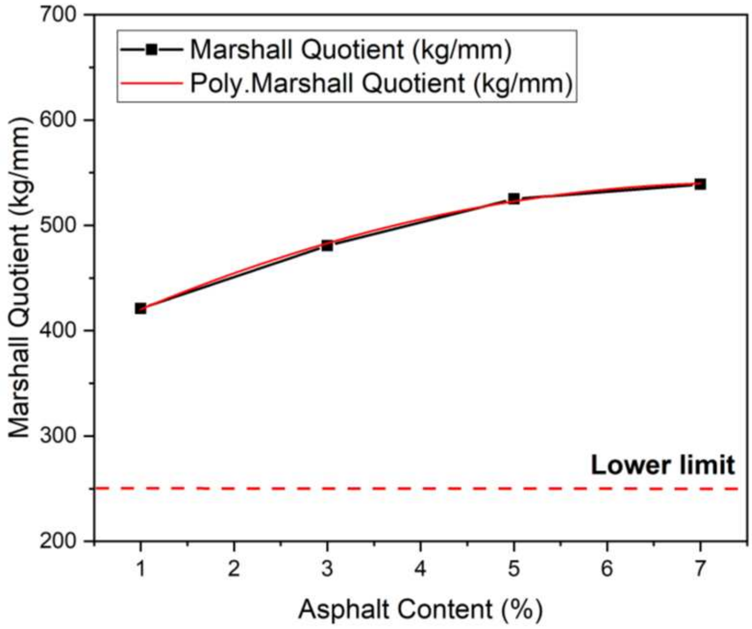

Figure 9. Graph of the Relationship Between MQ and Mixture of Plastic Bottles

So in this study, it can be concluded that the effect of adding PET in the Laston AC-WC mixture on the Marshall parameters, namely:

a. The VMA value has increased, indicating that the addition of PET will cause the aggregate coating to expand so that the waterproof hardening layer is not easily oxidized or damaged, and the mixture will become denser.
b. The VIM value has increased, indicating that PET is sticking to the aggregate to cover the voids. VIM value that is too small causes blending when the temperature increases.
c. The higher the VFA value, the more air-filled cavities are filled with asphalt to be more airtight.
d. The stability value increases as the PET mixture increases and decreases which is not significant. The stability value increases due to the enlarged aggregate and good adhesion, causing strong interlocking between grains. Meanwhile, the decrease in stability is caused by the excessive pushing of asphalt mastic.
e. The melting value increased with increasing the PET mixture. This indicates that the PET content of the Laston AC-WC mixture with the added ingredient Polyethylene Terephthalate (PET) is plastic.
f. The Marshall Quotient value has increased. This is influenced by the value of stability and flow in the mixture. Large stability values and small flows produce rigid specimens.

CONCLUSION

From the results of research on the Effect of PET (Polyethylene Terephthalate) Additives on Marshall Characteristics of Asphalt AC-WC conducted at the Transportation and Remote Sensing Laboratory, Campus of Brawijaya University, Malang, the following conclusions can be drawn:

1. The value of the Laston AC-WC characteristics can be obtained through Marshall tests and calculations. The asphalt content of 5%, 6%, and 7% have met the 2018 Highways specifications.
2. The Marshall Quotient values for the Laston AC-WC mixture with Polyethylene Terephthalate (PET) added at levels of 1%, 3%, 5%, and 7% are 525.121 kg/mm, 565.596 kg/mm, 539.026 kg/mm and 421.076 kg/mm. From these results, it can be seen that

the MQ value has decreased and increased. However, all MQ values are above the minimum limit for MQ values, namely 250 kg/mm.

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