Utilization of Plastic Bottles Waste in Asphalt Concrete Mixture

Machsus Machsus, Rachmad Basuki, Amalia Firdaus Mawardi, Mohamad Khoiri, Sukobar, Moh. Firli Firdausi
Department of Civil Infrastructure Engineering, Institut Teknologi Sepuluh Nopember Surabaya, Indonesia
machsusfawzy@gmail.com

Abstract. This paper deals with the innovation of road construction materials by the use of polyethylene terephthalate (PET) as asphalt mixtures. The PET was obtained from plastic bottles waste. The purpose of this research is to investigate the effects of the PET on Marshall parameters on asphalt concrete pavement. The wet method is used in this research. It means that PET plastic material is directly mixed into asphalt when the asphalt is heated, then aggregates are added. In this research, asphalt with penetration of 60/70 is used. Its optimum asphalt content (OAC) is 5.7 percent while The percentages of the added PET are 3 percent, 4 percent, 5 percent, 6 percent, and 7 percent of the asphalt by weight. The results show that the addition of PET plastic waste into the mixture has a significant positive effect on the Marshall parameters of asphalt concrete pavement. The addition of PET waste has been able to increase the value of other Marshall parameters, including Voids in Mix (VIM), Voids in Mineral Aggregates (VMA), Voids Filled with Asphalt (VFA), Flow, and Marshall Quotient (MQ). This research result will contribute to a significant outcome in emerging a sustainable material for road infrastructure. Keywords: plastic bottles waste, polyethylene terephthalate, asphalt concrete, Marshall parameters

1. Introduction
The early damage on road pavement is usually caused by the quality of asphalt and concrete mixing. An asphalt quality improvement on asphalt concrete mix is needed to prevent the early damage on road pavement [1]. An asphalt quality improvement could be done by utilizing the plastic bottle waste materials as the additional binder in the mix.

Based on the database from Directorate General of Waste Management and Harmful Substance, KLHK (2016), the plastic waste volume was estimated at 9.5 million tons per year and was equal to 14% of total plastic waste in the entire nation of Indonesia. Therefore, the utilization of plastic waste materials for road pavement is a good way to diminish the volume of the plastic waste [2], [3].

The plastic waste material which was used during this research was the Polyethylene Terephthalate (PET) type. PET is the outcome material from a condensation process of ethylene glycol polymer and terephthalate acid which was easy to find on fossil fuel. PET is constructed from ethylene terephthalate monomer which has a molecular formula of C10H8O4. PET has transparent and clear characteristics. It is resistant towards the organic solvent and has a variety of meting points ranging from 110 °C to 137 °C [4], [5], [6].
The utilization of additive on asphalt concrete mix was aimed to improve the quality of the road pavement itself. The utilization of Polyethylene Terephthalate at 6% to 18% by optimum asphalt content (OAC) could decrease the deformation on road pavement as well as increase the fatigue resistance and adhesiveness of asphalt and its aggregate [1], [5], [7], [8].

The Asphalt Concrete-Wearing Course (AC-WC) is a layer on the flexible pavement which is composed from the hardened asphalt and continuous aggregate mix which is compressed under a certain heat temperature. The mechanical strength from this mix was acquired from its internal friction which was influenced by the physical characteristic of aggregates used and it could be measured from its granular form and its surface texture [9], [10]. This research will mainly discuss about the influence of PET addition on Marshall characteristics from AC-WC mix.

2. Materials and Methods

2.1. Materials

The materials which were used during this research were PET waste materials, asphalt, Portland cement, and combined aggregates. The combined aggregates were coarse, medium, and fine aggregates. The fine aggregates were acquired from the fly ash and filler. Table 1 portrays the detail gradation of the combined aggregate along with its specification. The aggregate gradation standard code which was used for asphalt concrete-wearing course (AC-WC) was using the SNI standard code from Indonesia.

Based on the analysis on the combined aggregate, which followed the AC-WC specification, it has resulted in the final composition of 12% coarse aggregate, 48% medium aggregate, 38% of fine aggregate, and 2% of filler.

| Sieve Size | CA* | MA* | Fly Ash (FA*) | Filler (FF*) | Result | Specification |
|------------|-----|------|---------------|-------------|--------|---------------|
|            | 10-10 mm | 5-10 mm | 0-5 mm | 2 | AC | AC |
| 3/4" | 100 | 12 | Passing (%) | 12 | 100 | 2 | 100 | 100 |
| 1/2" | 28,57 | 3,42 | 99,58 | 47,79 | 100 | 38 | 100 | 2 | 91 | 90-100 |
| 3/8" | 10,18 | 1,22 | 98,28 | 47,17 | 100 | 38 | 100 | 2 | 88 | 77-90 |
| No.4 | 7,65 | 0,91 | 47,59 | 22,84 | 97,65 | 37,10 | 100 | 2 | 63 | 53-69 |
| No.8 | 0 | 0 | 8,67 | 4,16 | 81,40 | 30,93 | 100 | 2 | 37 | 33-53 |
| No.16 | 0 | 0 | 6,76 | 3,24 | 42,09 | 15,99 | 100 | 2 | 21 | 21-40 |
| No.30 | 0 | 0 | 6,52 | 3,12 | 28,42 | 10,79 | 100 | 2 | 16 | 14-30 |
| No.50 | 0 | 0 | 0,00 | 0 | 21,60 | 8,20 | 100 | 2 | 10 | 9-22 |
| No.100 | 0 | 0 | 0,00 | 0 | 11,12 | 4,22 | 100 | 2 | 6 | 6-15 |
| No.200 | 0 | 0 | 0,00 | 0 | 7,75 | 2,945 | 100 | 2 | 5 | 4-9 |

*CA: The percentage of aggregate which stayed at filter number 8.
*MA: The percentage of medium aggregate which had diameter range of 5 to 10 mm which stayed at filter number 30.
*FA: The percentage of aggregate which stayed at filter number 8 yet stayed at filter number 200.
*FF: The percentage of aggregate which 75% passed the filter number 200.

Table 2 below will explain more about the result of the physical test for the combined aggregate. The asphalt which has 60/70 penetration grade was used during this whole research [4], [12]. This particular asphalt type was qualified to be used based on the series of laboratory tests. The results of asphalt physical and chemical test which followed the specification and standard code could be found on Table 3 below.
Table 2. Combined aggregate physical test.

| No | Physical Test          | Standard Code          | Limit | Result | Note    |
|----|------------------------|------------------------|-------|--------|---------|
|    | **Coarse Aggregate (10-10mm)** |                       |       |        |         |
| 1  | Water Absorption       | SNI 03-1969-1990       | < 3%  | 1,69%  | Qualified |
| 2  | Density                | SNI 03-1970-1990       | ≥ 2,5 | 2,48%  | Qualified |
| 3  | Wear and Tear          | SNI 03-2417-1991       | ≤ 40% | 23,65% | Qualified |
|    | **Medium Aggregate (5-10mm)** |                   |       |        |         |
| 1  | Water Absorption       | SNI 03-1970-1990       | < 3%  | 1,64%  | Qualified |
| 2  | Density                | SNI 03-1970-1990       | ≥ 2,5 | 2,56%  | Qualified |
|    | **Fine Aggregate (0-5mm)** |                     |       |        |         |
| 1  | Water Absorption       | SNI 03-1970-1990       | < 3%  | 1,49%  | Qualified |
| 2  | Density                | SNI 03-1970-1990       | ≥ 2,5 | 2,51%  | Qualified |
|    | **Filler (Portland Cement)** |                 |       |        |         |
|    | 1. Density             | SNI 03-1970-1990       | ≥ 2,5 | 2,70   | Qualified |

Table 3. Asphalt physical and chemical test result.

| No | Physical and Chemical Test | Standard Code          | Specification Min. | Specification Max. | Result |
|----|---------------------------|------------------------|--------------------|--------------------|--------|
| 1  | Penetration               | SNI 06-2456-1991       | 60                 | 79                 | 70,08  |
| 2  | Softness Point            | SNI 06-2434-1991       | 48                 | 58                 | 56     |
| 3  | Flash Point               | SNI 06-2434-1991       | 200                | 0                  | 210    |
| 4  | Ductility                 | SNI 06-2434-1991       | 100                | -                  | 125    |
| 5  | Weight Loss               | SNI 06-2440-1991       | -                  | 0,8                | 0,038  |
| 6  | Density                   | SNI 06-2432-1991       | 1                  | -                  | 1,029  |

2.2. Methods

This research mainly used the laboratory-based experimental approach. The PET addition will play a variable change role during this research. There are two different methods in additive addition for the asphalt mix, which are dry and wet methods-based method of mixing. This research used the wet-based mixing process [2], [6], [8]. During this mixing process, PET particles were added into the hot mix of asphalt, during which it is important to make sure that the PET particles are well-blend with the entire mix and create a homogeneous substance. Furthermore, the combined aggregate is then mixed together with asphalt binder and PET particles [13], [14].

The percentage calculations of optimum asphalt content (OAC) which used the asphalt composition are as follows: 4.2%, 5.2%, 5.7%, 6.2%, and 7.0%. All these percentages are calculated based on an aggregate weight of 1200 grams. Based on the Marshall test results the value of OAC can be known and set to 5.7%.

The asphalt mix with PET addition used the designed optimum asphalt content (OAC) of 5.7%. Then PET particles were added to the mix with the variable ratios of 3%, 4%, 5%, 6%, and 7%. The aggregate mass was 1200 grams for each sample. Finally, all the sample preparations used the SNI 06-2489-1991 standard code.

3. Results and Discussions

3.1. Optimum Asphalt Content Calculation

The parameters which are important to consider in optimum asphalt content (OAC) calculation are density, VIM (Void in Mix), VFA (Void Filled Asphalt), VMA (Void in Mineral Aggregate), Marshall
Flow, Marshall Stability, and Marshall Quotient. The result of Marshall parameters is further explained below.

**Figure 1.** The relationship of density and asphalt content.

Figure 1 explains that the addition of asphalt content could increase the density value. The lowest average value of density was reached at 2.264 gr/cc for 4.7% asphalt content. The density values between sample 1 and sample 2 were different, but the average values of both were increased as more asphalt content was added. The highest average value of density was 2.273 gr/cc for 6.7% asphalt content. The relationship of density and asphalt content confirmed the previous research, which has been done by Widojoko and Purnamasari [11].

**Figure 2.** The relationship of void in mix (VIM) and asphalt content.

Figure 2 portrays that the addition of asphalt content could decrease the VIM value. The highest average value of VIM was obtained at 4.97% for 4.7% asphalt content. The average value of VIM decreased by adding the asphalt content. The lowest average of VIM value was at 2.53% for 6.7% asphalt content. The relationship of VIM and asphalt content confirmed the accountability of the previous research, which has been done by Hassani et al. [7].

Figure 3 describes that each sample tends to have similar VFA graph trend. The more asphalt content it has the more VFA value is obtained. The lowest average value of VFA was at 68% for 4.7% asphalt content. That value tends to increase as the asphalt content increases. The highest value of average VFA was at 85.3% for 6.7% asphalt content. The relationship of VFA and the asphalt content were relevant to the previous research which stated that the addition of asphalt content could increase the VFA value. In addition, the rise on asphalt content could also increase the filled pore on asphalt itself [11], [12].
Figure 3. The relationship of void filled asphalt (VFA) and asphalt content.

Figure 4. The relationship of void in mineral aggregate (VMA) with asphalt content.

Figure 4 describes that the more asphalt content there is the more void in mineral aggregate is found. The lowest average value of VMA was at 15.34% for 4.7% asphalt content. The value tends to increase as the more asphalt concrete is added. The highest average of VMA was at 17.29% for 6.7% asphalt content [12].

Figure 5. The relationship of flow and asphalt content.

Figure 5 shows that the addition of asphalt concrete could decrease the value of Marshall flow up to 5.7% of asphalt content. Then the graph was bounced back at 6.7% of asphalt concrete. The highest
average value of flow was at 4.5 mm for 4.7% asphalt content, while the lowest average value of flow was reached at 3.85 mm for 5.7% of asphalt content.

Figure 6. The relationship of Marshall stability and asphalt content.

Figure 6 describes that the Marshall stability was increased as the asphalt concrete was increased at the value of 5.7%, then the trend went down at the value of 6.7%. The highest average value of stability was achieved at 1.464 kg for 5.7% of asphalt content. While the lowest average value of stability was reached at 1.020 kg for 6.7% of asphalt content.

Figure 7. The relationship of Marshall quotient and asphalt content.

Figure 7 shows that the Marshall quotient increased with the addition of asphalt content at 5.7%, then went back down to 6.7%. The relationship of MQ and asphalt content confirmed the previous researches [12], [13], [14]. Table 4 below will present the summary of Marshall test parameters to determine the optimum asphalt content. Based on the analysis in the table below, it was concluded that the optimum asphalt concrete was 5.7%.
Table 4. The value of optimum asphalt content based on the Marshall test parameters.

| Marshall Parameter | Specification | Range       | Optimum Asphalt Content (OAC %) |
|--------------------|---------------|-------------|---------------------------------|
| STABILITY          | > 1000 kg     | 4.7 - 6.7   |                                 |
| FLOW               | > 3 mm        | 4.7 - 6.7   |                                 |
| VIM                | 3.0 - 5.5%    | 4.7 - 6.7   |                                 |
| VFA                | > 65%         | 4.7 - 6.7   |                                 |
| VMA                | > 15%         | 5.2 - 6.7   |                                 |
| MQ                 | >300 kg/mm    | 4.7 - 6.2   |                                 |

Designed Asphalt Content (%) | 4.7 | 5.2 | 5.7 | 6.2 | 6.7 |
Optimum Asphalt Content (%)  | 4.7 | 4.7 | 5.7 | 5.7 | 5.7 |

3.2. The Utilization of PET Waste in AC-WC Mixture

The percentage ratios of PET waste material addition were 3%, 4%, 5%, 6%, and 7% by the optimum asphalt content weight. This PET additional particle could decrease the total weight of the asphalt on Asphalt Concrete-Wearing Course, AC-WC. Below is the result of Marshall parameter test for AC-WC mixture with the variation of PET waste material addition.

Table 5. Marshall parameter test result with and without the plastic variation content

| Marshall Parameter | Specification | Without PET addition | With PET addition |
|--------------------|---------------|-----------------------|-------------------|
| STABILITY          | >1000 kg      | 1464                  | 1869              |
| FLOW               | > 3 mm        | 3,85                  | 5,6               |
| VIM                | 3.0 - 5.5%    | 4,02                  | 3,27              |
| VFA                | > 65%         | 75,77                 | 79,4              |
| VMA                | > 15%         | 16,56                 | 15,9              |
| MQ                 | >300 kg/mm    | 381                   | 334               |

Plastic Variation (%) | 0.0 | 3.0 | 4.0 | 5.0 | 6.0 | 7.0 |
Optimum Asphalt Content (%) | 5.7 |

Based on Table 5 analysis, the overall Marshall parameter test result for Asphalt Concrete-Wearing Course (AC-WC) without PET addition showed a smaller value of average stability compared to the one which uses the PET. Yet both variables followed the specification rule of having a stability value over 1000 kg.

Aside from that, the Marshall Parameter Test Result showed that the Asphalt Concrete-Wearing Course which has no PET addition has a lower Marshall flow value compared to those which have PET addition. Yet both variables followed the specification rule of having a Marshall flow of 3 mm.

Based on the VIM parameter, both Asphalt Concrete-Wearing Course (AC-WC) with and without PET addition followed the requested specification, as both samples obtained VIM at the range of 3.0 to 5.5%. Whilst for VFA, the AC-WC mix, which has no PET addition, has a smaller value of VFA compared to those which have PET addition. Yet both samples followed the specification of having a VFA value above 65%. Based on VMA parameter, it could be implied that the AC-WC mix, which has no PET addition, could yield into a higher VMA value compared to those which have PET addition. Yet both samples followed the specification of having a VMA value over 15%. The Marshall quotient test showed that both samples obtained a value of more than 300kg/mm. Therefore, both samples followed the requested specification.

4. Conclusions

Based on the literature review, analysis, and discussion, it is concluded that: (i) The composition of combined aggregate from the AC-WC mix could be formulated as follows: 12% of coarse aggregate, 48% of medium aggregate, 38% of fine aggregate, and 2% filler; (ii) The optimum asphalt content (OAC) was obtained at 5.7% based on the Marshall parameter test result variable. This OAC value will be then used as the reference value for the further PET addition variation ratios at 3%, 4%, 5%, 6%, and 7%; (iii) The result of Marshall Parameter Test specification on AC-WC mix, which has no
PET addition, was then proved to meet the Indonesian standard code of SNI; (iv) The result of Marshall Parameter Test specification on AC-WC mix, which has the variation of PET addition ratio, was also proved to meet the Indonesian standard code of SNI; (v) This research result will contribute to a significant outcome in emerging a sustainable material for road infrastructure.

Acknowledgment
The authors would like to express their gratitude to the reviewers for their constructive remarks. We also would like to thank the Institut Teknologi Sepuluh Nopember (ITS) Surabaya for the financial support provided through Laboratory Research Grant.

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