The effects of low-density polyethylene (LDPE) addition to the characteristics of asphalt mixture

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Abstract. Improving the quality of asphalt by adding additives like polymers, one of which is Polyethylene mixed in the AC-WC asphalt mixture. This research aims to determine the effect of adding Polyethylene on the characteristics of AC-WC asphalt mixture and bitumen properties. Polyethylene used is the Low-Density Polyethylene (LDPE) type, especially thin plastic bags with 0%, 4%, 5%, 6%, 8%, 10%, 15% and 20% contents of the asphalt weight. The Marshall Test is conducted to determine the value of stability and flow, and the Wheel Tracking Machine (WTM) Test is conducted to determine the value of dynamic stability and the rate of deformation of the asphalt mixture. The results show that the addition of LDPE can improve the performance of the asphalt mixture. The addition of 6% LDPE shows the optimum quality seen from the Marshall Test parameters. In the WTM Test, it found that the addition of 6% LDPE was increasing the value of dynamic stability and decreasing the rate of deformation. It shows that the addition of 6% LDPE can improve the performance of the asphalt mixture in receiving repeated loads due to tire repetition, as well as increasing crack resistance.

1. Introduction

The method that is often used to increase the quality of asphalt is by adding additives, such as polymers, plastics, charcoal or known as modified asphalt [1]. The addition of polymers usually increases the stiffness of bitumen and increases temperature susceptibility. The polymers used as an additive divided into two types, plastomers and elastomers. Polyethylene (High Density Polyethylene, Low Density Polyethylene or Polyethylene Terephthalate) are type of plastomers. The use of polyethylene in asphalt mixture can reduce road deformation, increase fatigue resistance and provide better adhesion between asphalt and aggregate [2].

Low-Density Polyethylene (LDPE) is one type of Polyethylene that recycled and suitable for goods with a high degree of flexibility [3]. This research uses LDPE material, lightweight plastic bag waste as additional material to the asphalt mixture. The use of plastic bag waste is a solution for handling plastic waste. LDPE waste used must be processed products that have been sorted, chopped and washed. Plastic waste cuts used must be dry, clean and free of organic or unwanted material [4].

Research on the effect of adding LDPE to the asphalt mixture has been carried out, such as the use of Polyethylene in Hot Asphalt Mixtures with the use of Polyethylene contents of 6%, 8%, 10%, 12%, 14%, 16% and 18% [2], as well as Effect of Polythene Modified Bitumen on Properties of Hot Mix Asphalt with the use of LDPE contents of 2.5%, 5%, 7.5%, 10%, 12.5% and 15% [5]. In this research, the author wanted to find out how is the effect of adding LDPE mixed in the AC-WC asphalt mixture.
2. Literature review

2.1. Modified asphalt
Modified asphalt is a hardened asphalt added with an additional material which aims to improve the performance of the desired asphalt. Initially, modified asphalt was introduced abroad to prevent cracks during the winter season, and modifications were made to prevent softening of concrete asphalt due to the heat of the road surface in the country with extreme summers. The most commonly used method of modifying asphalt is by using additives on asphalt mixtures. The addition of small quantities of polymer type additives into the asphalt proved to be able to improve the performance of asphalt and extend the strength/service life of the pavement [6]. Polymers can also increase the durability of the pavement against various damages, such as permanent deformation, cracks due to changes in temperature, fatigue damage and separation/release of materials [7]. Polymers divided into two types, elastomer (rubber) and plastomer (plastic).

2.2. Low-density polyethylene (LDPE)
Plastomers or plastics are additives that functioned to increase the softening point and thickness. As with elastomers, plastomers can also increase the softening point to reach 55°C, but the penetration rate drops dramatically. Polyethylene or with its generic name thermoplastic is one type of plastic that is relatively safe to use for food. One type of Polyethylene is Low-Density Polyethylene (LDPE), in the form of lightweight plastic bags, food containers, and glass-sized beverage containers. LDPE is stiff, slightly translucent, flexible, resistant to chemical compounds below 60°C and has high protection against water. LDPE can be recycled and is quite good if it used as a food container, which is difficult to react chemically with food packed with this material [3]. LDPE waste used must be processed products that have been sorted, chopped and washed. Plastic waste used must be dry, clean and free of organic or unwanted material [4].

2.3. Marshall test
Marshall Test aims to determine the characteristics of the asphalt mixture and optimum asphalt content. This test refers to AASHTO T 245-97 (2004). Test samples in Marshall Test are cylindrical with a thickness of 63.5 mm and a diameter of 102 mm which is tested at a temperature of 60°C and be given loading until a failure occurred. This test aims to determine the stability and flow of asphalt mixtures by measuring mixture resistance and determining the shape changes that occur due to traffic loads [8].

2.4. Wheel tracking machine (WTM) test
Wheel Tracking Machine (WTM) Test simulates the traces of wheel trails due to heavy vehicles at high temperatures on the highway so that the durability of hot asphalt mixtures can be evaluated and also evaluate the resistance of asphalt mixtures to permanent deformation. The test material prepared for this test has a composition and density that is designed like Marshall Testing under optimum conditions, with dimensions of 30x30x5 cm. This test is carried out with a surface pressure of 6.4 ± 0.15 kg/cm² equivalent to the single axle load of 8.16 tons double wheels. Samples are tested for 1 hour as many as 1260 passing or 42 passing per minute. The test requires supporting tools, i.e. the mixer to mix the material and the roller compactor to compact the test material before the WTM Test [8].

3. Research method

3.1. Preparation and examination
The materials forming asphalt mixture prepared, i.e. asphalt, aggregate, filler and LDPE. Asphalt used is asphalt 60/70 penetration. The filler used is Portland Cement type I. LDPE used is in the form of lightweight plastic bag type that comes from processed plastic waste which has sorted, chopped and washed. Plastic waste cuts used must be dry, clean and free of organic or unwanted material, according to specifications [4]. Then, several examinations of the physical properties of asphalt and
aggregate did were both used in the asphalt mixture. Examination of the physical properties of asphalt which includes the examination of asphalt penetration, the examination of softening point, ductility and specific gravity; while the examination of aggregate physical properties includes the analysis of granules, specific gravity and absorption of coarse and fine aggregates, and abrasion.

3.2. Sampling

3.2.1 samples before OAC. Samples were for several tests to determine OAC is carried out by making ordinary samples (2x75 hits) and Percentage Refusal Density Test (2x400 hits). The samples in this test were prepared with five varied percentages: 5%, 5.5%, 6%, 6.5% and 7% asphalt contents with 6 specimens each. Whereas for Percentage Refusal Density (PRD) test samples uses three varied percentages: 5.5%, 6% and 6.5% bitumen contents with two specimens each, so there are 36 specimens in total. Before determining the OAC, the mean value (Pb) first determined as the limit for determining the asphalt content to be used, by using the formula:

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Pb = 0.035(\%CA) + 0.045(\%FA) + (0.18\%*FF) + K
\]

3.2.2 samples after OAC. Determination of the stiffness modulus of asphalt concrete done by using a mixture of OAC. After obtaining OAC, an OAC-based sample made which mixed with LDPE with the contents of 0%, 4%, 5%, 6%, 8%, 10%, 15% and 20% of the asphalt weight, with six specimens each for ordinary test samples. Then for PRD test samples with variations of 0%, 4%, 5%, 6%, 8%, 10%, 15% and 20% of the asphalt weight, with 3 specimens each. So the total samples were 72 specimens.

3.2.3 Samples for WTM test. There are two specimens for WTM Test: one specimen without the addition of LDPE and one specimen with the addition of LDPE. The specimen with the addition of LDPE test carried out at the optimum content obtained from the Marshall Test, which is the addition of LDPE with 6% content of the asphalt weight.

4. Results and analysis

4.1 results of materials examination

Results of materials examination that include the results of the physical properties examination of asphalt (penetration, softening point, specific gravity and ductility), can be seen in Table 1.

| No. | Examination Type            | Spec | 0   | 4   | 5   | 6   | 8   | 10  | 15  | 20  |
|-----|----------------------------|------|-----|-----|-----|-----|-----|-----|-----|-----|
| 1.  | Penetration 25°C (0.1mm)   | 40   | 66.8| 53.0| 38.4| 35.3| 26.7| 23.0| 15.2| 12.3|
| 2.  | Softening Point (°C)       | ≥54  | 48.0| 56.5| 61.0| 66.5| 92.5| >100| >100| >100|
| 3.  | Specific Gravity           | ≥1   | 1.015| 1.014| 1.015| 1.017| 1.016| 1.011| 1.009| 1.008|
| 4.  | Ductility (cm)             | ≥100 | 122.00| 21.15| 16.35| 13.00| 9.65| 8.00| 3.60| 2.75|

4.2 Results of samples testing

4.2.1 marshall test results before OAC. From formula (1) obtained Pb = 0.035(56.64) + 0.045(37.22) + (0.18%*6.14) + 1 = 5.8%. Marshall Test results before OAC showed in Table 2. From the Marshall Test results before OAC, shows that OAC value is 5.75%.
Table 2. Marshall test results of asphalt mixture before OAC.

| No. | Examination Type       | Asphalt Content (%) | Spec. |
|-----|------------------------|---------------------|-------|
|     |                        | 5.0  | 5.5  | 6.0  | 6.5  | 7.0  |       |
| 1.  | Density (%)            | 2.24 | 2.26 | 2.25 | 2.24 | 2.23 | -     |
| 2.  | Stability (Kg/cm²)     | 801.09 | 889.19 | 909.98 | 882.26 | 835.01 | Min. 800 |
| 3.  | Flow (mm)              | 3.00 | 3.27 | 3.33 | 3.43 | 3.50 | 2 – 4 |
| 4.  | Marshall Quotient (Kg/mm) | 267.03 | 272.20 | 272.99 | 256.97 | 238.57 | Min. 250 |
| 5.  | VMA (%)                | 15.62 | 15.53 | 16.21 | 17.18 | 17.86 | Min. 15 |
| 6.  | VFB (%)                | 68.41 | 76.65 | 79.86 | 81.37 | 84.10 | Min. 65 |
| 7.  | VIM (%)                | 4.95 | 3.68 | 3.28 | 3.23 | 2.85 | 3 – 5 |
| 8.  | Retained Stability (%) | 95   | 94   | 93   | 92   | 91   | Min. 90% |
| 9.  | VIM PRD (%)            | -    | 3.30 | 2.23 | 1.55 | -    | Min. 2 |

4.2.2 Marshall Test Results After OAC. Marshall Test results after OAC with the addition of LDPE with 0%, 4%, 5%, 6%, 8%, 10%, 15% and 20% contents of the asphalt weight can be seen in Table 3.

Table 3. Marshall test results of asphalt mixture after OAC.

| No | Exam. Type       | LDPE Content (%) | Spec. |
|----|------------------|------------------|-------|
|    |                  | 0    | 4    | 5    | 6    | 8    | 10   | 15   | 20   |       |
| 1  | Density (%)      | 2.28 | 2.28 | 2.27 | 2.27 | 2.27 | 2.27 | 2.27 | -    |       |
| 2  | Stability (Kg/cm2) | 1008 | 1354 | 1525 | 1586 | 1635 | 1577 | 1489 | 1477 | Min. 900 |
| 3  | Flow (mm)        | 3.03 | 3.30 | 3.27 | 3.17 | 3.10 | 2.93 | 2.83 | 2.77 | 2 – 4 |
| 4  | Marshall Quotient (Kg/mm) | 332 | 410  | 467 | 501 | 527 | 538 | 545 | 549 | Min. 250 |
| 5  | VMA (%)          | 15.03 | 15.07 | 15.11 | 15.13 | 15.23 | 15.26 | 15.27 | 15.36 | Min. 15 |
| 6  | VFB (%)          | 72.43 | 71.39 | 69.88 | 69.36 | 68.57 | 67.98 | 65.70 | 63.62 | Min. 65 |
| 7  | VIM (%)          | 4.16 | 4.31 | 4.55 | 4.64 | 4.79 | 4.89 | 5.24 | 5.59 | 3 – 5 |
| 8  | Retained Stability (%) | 90.57 | 92.13 | 93.02 | 93.55 | 90.52 | 86.63 | 84.32 | 82.24 | Min. 90% |
| 9  | VIM PRD (%)      | 2.03 | 2.37 | 2.54 | 2.71 | 2.85 | 2.99 | 3.08 | 3.15 | Min. 2 |

From Table 3, it shows that the addition of LDPE with contents of 4%, 5%, 6% and 8% in the asphalt mixture meets the specification requirements, while the addition of LDPE with contents of 10%, 15% and 20% does not meet the specification requirement [4]. It shows that there is a need to limit the addition of LDPE contents because a higher addition of LDPE contents will give results that do not meet the specifications. Retained stability for the addition of LDPE with contents of 10%, 15% and 20% does not exceed 90% from the specifications.

An increase in the value of stability until the addition of 8% LDPE shows that the nature of the mixture will be stiffer and more susceptible to cracking. The higher the addition of LDPE contents, the lower the flow value produced so that asphalt mixture will be more rigid and brittle [9]. The addition of LDPE contents to the mixture also shows an increase in the values of VIM and VMA, as well as a decrease in the value of VFB. It shows that the cavities in the mixture and the space between the aggregates are getting bigger, so that asphalt can fill the space and bind to the aggregates [10].

Based on the value of Retained Stability, it showed that the addition of LDPE with 6% content shows the excellent quality of the asphalt mixture. It is following the research conducted by Balitbang and BBPJN VIII Surabaya (2017) [8] and implemented on several roads in East Java Province as a trial location. The use of 6% content is also by the content of use of plastic waste which recommended in the specification, i.e. 4-6% of the asphalt weight [4].

4.2.3 WTM test results. The WTM Test is carried out on a non-asphalt mixture (control) and with the addition of 6% LDPE, because the 6% content is the excellent quality content obtained from the Marshall Test. The WTM Test results showed in Table 4.
From Table 4, it seems that the addition of 6% LDPE gives an increase in the value of Dynamic Stability compared to the absence of LDPE; it is significant with the decreasing Rate of Deformation value if the addition of the contents of LDPE increases. The two WTM parameters meet the General Specifications of Bina Marga Revision III Tahun 2010 [11]. This is in accordance with the research of Teknologi Campuran Beraspl Menggunakan Limbah Plastik (2017) [12] and research of Penerapan Skala Penuh Teknologi Aspal Limbah Plastik (2017) [8], where the two kinds of research shows that as the amount of LDPE increases to the asphalt mixture then the value of the dynamic stability produced is more significant. It shows that the addition of LDPE could improve the performance of the asphalt mixture in receiving repeated loads due to tire repetition and increasing crack resistance.

5. Conclusion
The addition of LDPE to the AC-WC asphalt mixture causes an increase in the value of stability to the content of 8%, then decreases after that. It shows that there is a need for restrictions in the use of LDPE. In the flow value, it decreases with increasing contents of LDPE, where the nature of the mixture becomes more rigid and brittle so that the mixture will be more easily experience cracking. As the addition of LDPE to the asphalt mixture is decrease, the VIM and VMA values also increase. However, on the contrary, the value of VFB decreases with increasing contents of LDPE.

The Retained Stability parameter shows that there is an increase until the addition of 6% LDPE and decreases after that. Based on Marshall parameters, the test shows that the addition of 6% yields the excellent quality of the asphalt mixture and is following the requirements of Spesifikasi Khusus Interim Campuran Beraspl Panas Menggunakan Limbah Plastik Tahun 2017 (Special Specifications for Interim Hot Paved Mixtures Using Plastic Waste, 2017), i.e. the use of LDPE in asphalt mixture of 4-6% of asphalt weight.

From the results of the WTM Test, it found that the addition of 6% LDPE in the asphalt mixture shows a higher value of Dynamic Stability than without the addition of LDPE. The Rate of Deformation produced in the asphalt mixture with the addition of 6% LDPE is lower so that the asphalt mixture is more resistant to deformation. It proves that the mixture with the addition of LDPE can improve the performance of the asphalt mixture in receiving repeated loads due to tire repetition and increasing crack resistance.

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