Effect of Compaction Temperatures on Marshall Properties on Hot Rolled Sheet-Base mixture with the addition of plastic waste

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Abstract. This paper studies the effect of compaction temperatures on Marshall properties on a Hot Rolled Sheet-Base (HRS-Base) mixture with the addition of plastic waste. Polyethylene terephthalate (PET) type plastic waste from plastic bottle waste is used in this study as an additional material of HRS-Base mixture. The ‘wet method’ is used to mix the PET into HRS-Base mixture, in which the PET is pre-mixed with asphalt material at the temperatures between 160 °C to 170 °C to create modified asphalt before it is mixed with HRS-Base aggregates. The materials used in this study consist of PET from plastic bottle waste, 60/70 penetration asphalt, Portland cement, and aggregates. The aggregate composition used must meet HRS-Base specifications based on the Indonesian National Standard (SNI). The results showed that increasing the compaction temperature of the HRS-Base mixture had an impact on increasing density, Voids Filled with Asphalt (VFA), Marshall stability, and Marshall Quotient (MQ), while the values of Voids in Mix (VIM), Voids in Mineral Aggregates (VMA), and Flow decreased. In addition, HRS-Base without the addition of PET plastic (conventional HRS-Base) and HRS-Base with the addition of PET plastic (modified HRS-Base) were compared. Conventional HRS-Base has a density value, Voids Filled with Asphalt (VFA), and Flow higher than those of modified HRS-Base. While, the value of Voids in Mix (VIM), Voids in Mineral Aggregates (VMA), and Marshall stability of conventional HRS-Base are lower than those of modified HRS-Base. Keywords: Polyethylene Terephthalate (PET), Hot Rolled Sheet-Base, Marshall Properties, Compaction Temperature

1. Introduction
Nowadays, plastic waste is one of the serious environmental problems in many countries in the world. Cities in the world produce 1.3 billion tons of plastic waste every year [1]. In the management of plastic waste, innovation is needed so that the amount of plastic waste in Indonesia can be reduced. Utilization of plastic waste into building structure or road material are a rational approach [2-6].

Researchers have conducted many methods to utilize plastic waste as an addition of road material [3-6]. One of the methods is the innovation of mixing Polyethylene Terephthalate (PET) plastic waste in asphalt mixture. Asphalt mixture is a bonding agent of flexible pavement material. Polyethylene Terephthalate (PET), a type of plastic commonly used for single use drinking bottles of mineral water, is used as an addition material to create a modified asphalt. The addition of Polyethylene
Terephthalate (PET) plastic waste to the asphalt mixture also could be turn out improvement in some parameters of asphalt. Then the benefit is not only reusability of plastic waste into road material but also reduction of the amount of asphalt in the road material mixture.

The process of mixing asphalt with the plastic requires a high temperature, 160 °C to 170 °C, to achieve homogeneous conditions of the modified asphalt. That mixing method is used in this study. Furthermore, the modified asphalt is mixed with the aggregate to create Hot Rolled Sheet-Base (HRS-Base) mixture. In other side, compaction temperature also influences the characteristics of Marshall test results, an essential property of pavement material of HRS-Base. Therefore, it is necessary to conduct research on the effect of compaction temperature on Marshall properties on a Hot Rolled Sheet-Base (HRS-Base) mixture with the addition of plastic waste, specifically for the type of polyethylene terephthalate (PET). The Marshall test properties evaluated in this research are density, Voids Filled with Asphalt (VFA), Marshall stability, Marshall Quotient (MQ), Voids in Mix (VIM), Voids in Mineral Aggregates (VMA), and Flow. In addition, HRS-Base without the addition of PET plastic (conventional HRS-Base) and HRS-Base with the addition of PET plastic (modified HRS-Base) were also compared.

2. Materials and Methods

2.1. Materials

The materials used in this study are plastic bottle waste, asphalt penetration 60/70, Portland cement, and aggregate. The aggregate size used consists of coarse aggregate (10-10mm), medium aggregate (5-10mm), and fine aggregate (0-5mm). Table 1 illustrates the aggregate composition used for the HRS-Base mixture to achieve Indonesian National Standard (SNI) specifications. Based on aggregate combination analysis, proportion of the aggregate composition is as follows: 27% coarse aggregate, 20% medium aggregate, and 53% fine aggregate.

Tables 2 and 3 present the results of aggregate tests and asphalt tests used. Physical test for the aggregates, physical and chemical test for the asphalt were conducted. Those tests were required to pass the SNI code qualifications for HRS Base material. In this study, asphalt with 60/70 penetration is used.

| Table 1 The combined aggregate gradation and specification |
|---|---|---|---|---|---|---|
| Sieve No | Coarse Aggregate (CA 10-10mm) | | Medium Aggregate (MA 5-10mm) | | Fine Aggregate (FA 0-5mm) | Mixed Aggregate |
| % Passing | % Passing | % Passing | % Passing | % Passing | % Passing | % Passing |
| % Passing | | | | | | |
| 3/4" | 100.00 | 27.00 | 100.00 | 20.00 | 100.00 | 53.00 | 100.00 | 100 |
| 1/2" | 97.56 | 26.34 | 100.00 | 20.00 | 100.00 | 53.00 | 99.30 | 90 | 100 |
| 3/8" | 53.29 | 14.39 | 97.76 | 19.55 | 100.00 | 53.00 | 86.90 | 65 | 90 |
| #4 | 5.22 | 1.41 | 43.79 | 8.76 | 100.00 | 53.00 | 63.20 | 49 | 72 |
| #8 | 0.79 | 0.21 | 2.97 | 0.59 | 83.32 | 44.16 | 45.00 | 35 | 55 |
| #16 | 0.00 | 0.00 | 0.63 | 0.13 | 55.09 | 29.20 | 29.30 | 24 | 44 |
| #30 | 0.00 | 0.00 | 0.00 | 0.00 | 38.93 | 20.63 | 20.60 | 15 | 35 |
| #50 | 0.00 | 0.00 | 0.00 | 0.00 | 25.19 | 13.35 | 13.40 | 10 | 26 |
| #100 | 0.00 | 0.00 | 0.00 | 0.00 | 16.69 | 8.85 | 8.80 | 6 | 17 |
| #200 | 0.00 | 0.00 | 0.00 | 0.00 | 11.89 | 6.30 | 6.30 | 2 | 9 |

CA: The coarse aggregate which retained at sieve #8.
MA: The medium aggregate which had diameter range of 5 to 10 mm, which retained at sieve #30.
FA: The fine aggregate which retained at between sieve #200 and #8.
Table 2 Aggregate physical test

| Material Type            | Physical Test | Standard Code | Limit   | Result     | Note  |
|--------------------------|---------------|---------------|---------|------------|-------|
| Coarse Aggregate (10-10mm) | Water Absorption | SNI 03-1970-1990 | ≤3%     | 1.53%      | Qualified |
|                          | Density       | SNI 03-1970-1990 | >2.5 gr/cm³ | 2.697 gr/cm³ | Qualified |
| Medium Aggregate (5-10mm) | Water Absorption | SNI 03-1970-1990 | ≤3%     | 2.65%      | Qualified |
|                          | Density       | SNI 03-1970-1990 | >2.5 gr/cm³ | 2.697 gr/cm³ | Qualified |
| Fine Aggregate (0-5mm)   | Water Absorption | SNI 03-1970-1990 | ≤3%     | 2.18%      | Qualified |
|                          | Density       | SNI 03-1970-1990 | ≥2.5 gr/cm³ | 2.660 gr/cm³ | Qualified |
| Filler (Portland Cement) | Density       | SNI 03-1970-1990 | ≥2.5 gr/cm³ | 3.15 gr/cm³  | Qualified |

Table 3 Asphalt physical and chemical test

| No | Physical and Chemical Test | Standard Code | Specification Min. | Specification Max. | Result |
|----|----------------------------|---------------|--------------------|-------------------|--------|
| 1  | Penetration                | SNI 06-2456-1991 | 60                 | 79                | 72.3   |
| 2  | Softness Point             | SNI 06-2434-1991 | 48                 | 58                | 51.5   |
| 3  | Flash Point                | SNI 06-2434-1991 | 200                | 0                 | 244    |
| 4  | Ductility                  | SNI 06-2434-1991 | 100                | -                 | 167    |
| 5  | Weight Loss                | SNI 06-2440-1991 | -                  | 0.8               | 0.188  |
| 6  | Density                    | SNI 06-2432-1991 | 1                  | -                 | 1.036  |

2.2. Methods
The mixing method used to develop the modified asphalt material is by wet method, where PET is mixed with asphalt at temperatures between 160 °C to 170 °C. The mixing process is carried out at high temperatures, so that the modified asphalt will be produced in homogeneous conditions. The HRS-Base mixture is created by mixing the modified asphalt with HRS-Base aggregates at temperature 170 °C. Then the mixture is prepared into Marshall compaction mold at a specific temperature before it is compacted in compactor machine. The variation of compaction temperature becomes a variable in this study, because compaction temperature affects the Marshall properties, the essential properties of pavement material [3].

Variations of compaction temperature used in this study are 100 °C, 110 °C, 120 °C, 130 °C, 140 °C, 150 °C, 160 °C, 170 °C, and 180 °C. The optimum asphalt content (OAC) and the percentage of plastic addition refer to previous studies [4]. The optimum asphalt content (OAC) used is 7.3% with an additional plastic of 5% of the by weight of asphalt. The overall weight of the job mix formula (JMF) is 1200 gr. The study was conducted at the Transportation and Geotechnical Laboratory of the Institut Teknologi Sepuluh Nopember. The parameters obtained in this study are Marshall Stability, Flow, VIM (Voids in Mix), VMA (Voids in Mineral Aggregate), VFA (Voids Filled with Asphalt), and MQ (Marshall Quotient) [5-7].

3. Results and Discussions
The relationship between density and compaction temperature in Fig. 1 shows that the density value tends to increase with increasing compaction temperature in both conventional asphalt mixes and modified asphalt. HRS-Base mixture can experience optimal compaction at high temperatures, so the density value increases. Whereas, at low compaction temperatures, the density value is also low because it has many cavities that cannot be filled with asphalt. The relationship between density and temperature compaction is in accordance with the results of research by Shubham Meena et. al. (2018), which shows the same tendency [8].
Fig. 1 also shows that the density value of HRS-Base with modified asphalt is lower than conventional HRS-Base. Voids Filled with Asphalt (VFA) are increasingly reduced due to the use of asphalt modified with the addition of plastic waste, specifically for the type of polyethylene terephthalate (PET). The impact of reduced VFA results in the density level of the mixture of HRS-Base with modified asphalt also decreasing, thus, becoming lower than HRS-Base without plastic [9].

Fig. 2 shows that increasing compaction temperature can reduce Voids in Mix (VIM) for both conventional and modified HRS-Base mixes. However, both VIM values still meet the standard of Bina Marga (2018) which require a minimum VIM value for HRS-Base of 4% and a maximum of 6%. At low compaction temperatures, asphalt is difficult to cover the aggregate, so the percentage of voids in mix at HRS-Base is still large. This relationship strengthens the results of research conducted by Shubham Meena et al. (2018) and A. Sudikno (2018) with the same pattern of relationships. VIM value on HRS-Base with modified asphalt is higher than HRS-Base with conventional asphalt as shown in Fig. 2. In HRS-Base with modified asphalt, aggregate is covered by PET plastic content, so filling the voids in mix with asphalt cannot be optimal [8,9].
The value of Voids in Mineral Aggregate (VMA) on HRS-Base with the addition of PET plastic is higher than HRS-Base without the addition of PET plastic, as shown in Figure 3. The addition of PET plastic prevents asphalt from filling the cavity in the HRS-Base mixture. As a result, more and more voids in mineral aggregates are not filled with asphalt. A high percentage of VMA affects the grain attachment between aggregates to be easily separated [8,10,11].

Figure 3. The relationship of VMA and compaction temperature

Figure 4 shows that the value of Voids Filled with Asphalt (VFA) increases with increasing compaction temperature, but at 140 °C, the VFA value decreases for both conventional and modified HRS-Base mixtures. HRS-Base with conventional asphalt has a higher VFA value than HRS-Base with modified asphalt. This is due to the plastic added to the mixture, blocking the asphalt which should fill the cavity in the HRS-Base mixture [8,10,11].

Figure 4. The relationship of VFA and compaction temperature
Figure 5. The relationship of Marshall stability and compaction temperature

Figure 5 shows that the Marshall stability value increases with increasing compaction temperature and after achieving maximum stability it will decrease, both on HRS-Base with conventional asphalt and HRS-Base with modified asphalt. The graph above shows that the stability value increases with increasing temperature, but at a temperature of 150 °C, stability starts to decrease. The higher compaction temperature will facilitate the aggregate granules to be interrelated and covered by asphalt. HRS-Base stability value with the addition of PET plastic is higher than HRS-Base without the addition of plastic. The addition of plastic makes the adhesion between the modified asphalt and the aggregates interlock well, so that its stability increases because the aggregate's position does not easily shift when under load [8,12].

Figure 6. The relationship of Flow and compaction temperature

An increase in compaction temperature affects the decrease in Flow, both on HRS-Base with conventional asphalt and HRS-Base with modified asphalt as shown in Figure 6. In the graph above, it has been shown that the Flow value on HRS-Base with conventional asphalt is higher than HRS-Base with modification asphalt. This means that the value of Flow in HRS-Base without the addition of plastic is higher than HRS-Base with added plastic PET. Asphalt content in HRS-Base with conventional asphalt is certainly more than HRS-Base with modified asphalt. More asphalt content causes HRS-Base to be soft so that Flow is increased [8].
Figure 7. The relationship of MQ and compaction temperature

From Figure 7 it can be seen that an increase in the Marshall Quotient (MQ) value is along with the increase in compaction temperature. The graph above shows that the MQ value on HRS-Base with modified asphalt is higher than HRS-Base with conventional asphalt. This is because the stability value on HRS-Base with the addition of PET plastic is higher and the Flow value is also smaller than HRS-Base without the addition of plastic. However, the results of this study note that the average MQ value on HRS-Base with conventional asphalt does not meet the specifications, because it is below 250 kg/mm. In the Bina Marga Standard (2018), it is determined that the minimum MQ value is 250 kg/mm [8].

4. Conclusions
The study on effect of compaction temperatures on marshall properties on Hot Rolled Sheet-Base mixture with the addition of plastic waste has been conducted. Based on the literature review, analysis and discussion, it was concluded that:
• The composition of combined aggregate from the HRS-Base mix could be formulated as follow: 20% of coarse aggregate (10-10 mm), 27% of medium aggregate (5-10 mm), 53% of fine aggregate (0-5 mm);
• The increase in compaction temperature affects Marshall Properties both on HRS-Base with conventional asphalt and asphalt modification which that the value of density, Voids Filled with Asphalt (VFA), Marshall stability, and Marshall Quotient (MQ) are increased, while the value of Voids in Mix (VIM) and Voids in Mineral Aggregates (VMA) are decreased;
• Marshall Properties on HRS-Base without the addition of PET plastic (conventional) show that the density, Voids Filled with Asphalt (VFA), and Flow values are higher than HRS-Base with the addition of PET plastic (modification), while the values of Voids in Mix (VIM), Voids in Mineral Aggregates (VMA), and Marshall stability are lower.

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