The Effect of PET Plastic Addition (Polyethylene Terephthalate) and Carbide Waste Filler for Asphalt Concrete-Binder Course (AC-BC) on Marshall Characteristics

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Abstract. To improve the quality of infrastructure that is durable and solid, innovation needed to make sure the high quality of roads. This study aimed at knowing the effect of PET addition in the percentage of 0%, 1%, 1.5%, and 2% for asphalt concrete-binder course on Marshall characteristics, and revealing whether the results of Marshall testing with added PET material and carbide waste filler has fulfilled the general specification of Directorate General of Highway 2010. This study used PET plastic addition with variations of 0%, 1%, 1.5% and 2%. Each variation of PET content was made on 3 samples for objects testing to obtain values of density, VIM, VMA, VFA, stability, flow, and MQ. The results of this study indicated that the addition of PET plastic content and carbide waste filler affects the value of the asphalt characteristic of Marshall. The most effective addition was at 1% level with a density of 2.23 gr/cc, VIM value of 4.82%, VMA value of 14.58%, VFA value of 67.18%, flow value of 3.30 mm, stability value of 3060.42 kg and MQ value of 936.79 kg/mm. Overall, the addition of PET plastic and carbide waste filler to the characteristics of the marshall.

Keywords: asphalt, carbide waste, PET plastic

1. Introduction
Roads have been considered as the crucial element for the nation and state development. The availability of infrastructure is needed to support the national competitiveness, especially to boost export activities with low logistics costs. The infrastructure also plays a role to develop investment, either domestic or international.

In 2018, the Ministry of Public Works and Public Housing (PUPR) allocated 57% of IDR 41.6 trillion for Directorate General of Highways to maintain roads and bridges. In addition to preservation activities, they also build many new roads with the length of 829 km in coastal area of South Java, Kalimantan Border, NTT Border, Papua Border, and Trans Papua. The construction of new roads is focused to connect the strategic cross roads network, such as cross-border, Java and Trans Papua, at the end of 2019 [1].

However, damaged roads are often encountered, so it disturbs the traffic. There are some researches that has been done to improve road pavement. One of them are using PET plastic as an additional component. Indonesia Solid Association Waste explains that, in Indonesia, plastic waste is...
ranked second with 5.4 million tons per year or 14% of total waste production. It has been able to replace paper waste which was formerly in the second position with the total of 3.6 million tons per year or 9% of the total waste [2].

It is clear that the researches on asphalt are very beneficial in order to obtain its economical and durable mixture. This study is trying to use PET plastic as the additional components by determining its levels to each tested object with the percentage of 0%, 1%, 1.5%, and 2%. PET plastic was studied because of the big strength of the used plastic bottles [3 - 5]. This study is expected to enhance the value of Marshall stability that has been revealed in some previous studies.

This study also used different filler compositions. The filler is a fine-grained material passed the filter with number of 200 (0.075 mm) and it serves to reduce sensitivity to temperature and fill cavities of aggregates in asphalt concrete mixture. The filler of this study used carbide waste. It was chosen because it was easy to be obtained. Moreover, the cost was very low but it had high adhesive power. The use of carbide waste was also expected to increase the stability of Marshall and to reduce the pollution on the riverbanks.

Based on the issues above, this study aimed at revealing the effect of PET (Polyethylene Terephthalate) plastic addition and carbide waste filler for asphalt concrete-binder course (AC-BC) on marshall characteristics. The PET plastic may influence the high flexural strength and the carbide waste filler can increase Marshall stability.

2. Method

2.1 Research type
This study was done through the laboratory experiment to determine the effect of the different percentage of PET plastic addition, i.e. 0%, 1%, 1.5%, and 2% towards the mixture of asphalt concrete on Marshall characteristics. It was also to reveal whether the results of Marshall testing with added PET material and carbide waste as a filler had fulfilled the general specification from Directorate General of Roads and Highways [6].

2.2 Research variable
The research variables were divided into 3 types, namely independent, control, and dependent variables where each of those variables had mutual relationship. The independent variables included level and type of aggregate (rough and fine). The control variables consisted of asphalt content (6% of total aggregate), filler content (5% of total aggregate), mixing method of the specimen (wet method), asphalt type (from Pertamina), mixing temperature of test specimen (1600 °C), type of PET (number 1), number of compaction (75x), PET content (0%, 1%, 1.5%, and 2%). Meanwhile, the dependent variables referred to density, VIM, VMA, VFA, stability, flow, MQ (Marshall Quotient).

2.3 Research instruments
The research instrument used a test specimen of cylindrical concrete asphalt mixture. The specimens included control specimens and test objects with added PET plastic materials of 1%, 1.5% and 2% respectively. Marshall testing was carried out with the Marshall model of 76-B0038 / CB serial number of 06118321.
2.4 Data collection techniques
This research was conducted through experiments and specimens testing. It also employed library study by reviewing various literatures. Interviews with the laboratory experts on how to use laboratory equipment and materials correctly were also done.

2.5 Data analysis techniques
The data were analyzed with quantitative descriptive technique to determine the effect of PET Plastic Addition (Polyethylene Terephthalate) and Carbide Waste Filler for Asphalt Concrete-Binder Course (AC-BC) on Marshall Characteristics.

3. Results and discussion
Marshall testing aimed at knowing the density, VIM, VMA, VFA, flow, stability, and MQ (Marshall Quotient). In this study, 12 specimens were made with the different percentages of PET (Polyethylene Terephthalate) mixture. BK1 notation could be interpreted as control specimen 1, while 1P1 was interpreted as specimen 1 with the content of 1% PET. Meanwhile, 1.5P1 was as the specimen 1 with 1.5% PET, and 2P1 was the specimen 1 with 2% PET.
3.1 The results of density testing

| Notation | Density (gr/cc) | Mean (gr/cc) |
|----------|-----------------|--------------|
| BK1      | 2.26            |              |
| BK2      | 2.24            | 2.25         |
| BK3      | 2.25            |              |
| 1P1      | 2.22            |              |
| 1P2      | 2.26            | 2.23         |
| 1P3      | 2.21            |              |
| 1.5P1    | 2.19            |              |
| 1.5P2    | 2.27            | 2.22         |
| 1.5P3    | 2.19            |              |
| 2P1      | 2.21            |              |
| 2P2      | 2.22            | 2.21         |
| 2P3      | 2.19            |              |

Figure 2 showed that the level of PET additional material affected the density value. The density value of concrete asphalt mixture without PET addition was higher than the mixture with PET addition. When PET was mixed with asphalt on the temperature of 115 °C, the added plastic was not perfectly melted which was still in the form of fine fibers. Plastic was a thermoplastic material that had the high degree of flow at the temperature of 200 °C. At the same asphalt content, the higher the PET content addition, the less cavity filled with asphalt so that the pore content in the mixture was getting higher. It made the mixture with PET plastic became less dense than those without PET plastic.

The highest density value was 2.24 gr /cc in the mixture without added PET plastic, while the addition of PET plastic decreased. The addition of 1% PET content obtained the density value of 2.23 gr/cc, 1.5% PET content of 2.22 gr/cc and 2% PET content of 2.21 gr/cc.
3.2 The results of VIM (voids in the mix) testing

Table 2. Data of VIM testing

| Notation | VIM (%) | Mean (%) |
|----------|---------|----------|
| BK1      | 2.60    |          |
| BK2      | 3.72    | 3.17     |
| BK3      | 3.18    |          |
| 1P1      | 5.20    |          |
| 1P2      | 3.59    | 4.82     |
| 1P3      | 5.68    |          |
| 1.5P1    | 6.88    |          |
| 1.5P2    | 3.63    | 5.82     |
| 1.5P3    | 6.96    |          |
| 2P1      | 6.61    |          |
| 2P2      | 6.11    | 6.73     |
| 2P3      | 7.46    |          |

VIM was an air cavity in asphalt mixture and it was influenced by several factors including grain shape, surface texture, gradation, asphalt content, temperature, and density factor. The required VIM value was 3% -5%.

At levels of 0% and 1% PET, it had met the requirements in which each value was 3.35% and 4.82% respectively. Meanwhile, PET content of 1.5% and 2% with the value of 5.82% and 6.73% was not fulfilling the requirements because it exceeded the maximum limit set by the Directorate General of Highway[6].

Figure 3 below showed that the higher the PET level, the bigger the VIM value since the added PET levels blocked the asphalt to fill the cavity in the mixture. It means the more PET levels, the bigger the cavity was formed.
3.3 The results of VMA (Voids in Mineral Aggregate) testing

| Notation | VMA (%) | Mean (%) |
|----------|---------|----------|
| BK1      | 13,40   |          |
| BK2      | 14,39   | 13,90    |
| BK3      | 13,92   |          |
| 1P1      | 14,92   |          |
| 1P2      | 13,48   | 14,58    |
| 1P3      | 15,35   |          |
| 1,5P1    | 16,04   |          |
| 1,5P2    | 13,11   | 15,09    |
| 1,5P3    | 16,12   |          |
| 2P1      | 15,40   |          |
| 2P2      | 14,95   | 15,51    |
| 2P3      | 16,17   |          |

VMA was the percentage level of the cavity space between the aggregate particles in the tested object. The required VMA value was at least 14% based on the Directorate General of Highway requirements 2010. The following was the graph on the VMA comparison between the specimen with and without PET plastic.

In Figure 4, showed that the addition of PET content affected the value of VMA where the more PET content, the bigger VMA value was obtained. The value of VMA without the addition of PET plastic had the smallest percentage value, i.e 14.07%. Meanwhile, the highest VMA value was in the addition of 2% PET content with 15.51%. Then, the mixture with 1% PET obtained VMA value of 14.58% and 1.5% PET content of 15.09%. Based on these results, all tested materials had met the VMA value set by the Directorate General of Highways, at least 14%.

![Graph showing VMA score (%) vs PET content (%)](image-url)
3.4 VFA (Void Filled With Asphalt) testing results

Table 4. Data of VFA testing results

| Notation | VFA (%) | Mean (%) |
|----------|---------|----------|
| BK1      | 80.58   |          |
| BK2      | 74.16   |          |
| BK3      | 77.12   |          |
| 1P1      | 65.18   |          |
| 1P2      | 73.35   | 67.18    |
| 1P3      | 63.03   |          |
| 1.5P1    | 57.12   |          |
| 1.5P2    | 72.32   | 62.07    |
| 1.5P3    | 56.79   |          |
| 2P1      | 57.09   |          |
| 2P2      | 59.12   | 56.69    |
| 2P3      | 53.86   |          |

VFA was the cavity filled with asphalt in the mixture after undergoing the density process. Asphalt levels were the main factor in VFA value. The VFA value set by the Directorate General of Highways of 2010 was 65%. The results of the VFA test are presented in Figure 5.

Based on Figure 5, it can be seen that the increasing of PET levels affecting the decrease value of VFA. It was influenced by the mixing plastic that was not perfectly flowed and still in the form of fiber covering with asphalt. It reduce the amount of asphalt that should fill the cavity in the mixture.

The highest VFA value was at 0% PET content of 76.27%. Meanwhile, the level of 1% PET decreased by 9.09%, so that the VFA value of 67.18% was obtained. Then, 1.5% PET content with the value of 62.07% and 2% PET content had decreased by 5.38%, so that VFA value was 56.59%. Based on these results, it can be concluded that the levels 0% and 1% had fulfilled the requirements of Directorate General of Highways [6].

Figure 5. VFA (Void Filled With Asphalt)
3.5 Flow Testing results

| Notation | Flow (mm) | Mean (mm) |
|----------|-----------|-----------|
| BK1      | 4.20      |           |
| BK2      | 2.60      | 3.37      |
| BK3      | 3.30      |           |
| 1P1      | 3.20      |           |
| 1P2      | 3.00      | 3.30      |
| 1P3      | 3.70      |           |
| 1.5P1    | 3.20      | 3.23      |
| 1.5P2    | 3.20      | 3.23      |
| 1.5P3    | 3.30      |           |
| 2P1      | 2.50      |           |
| 2P2      | 3.00      | 3.10      |
| 2P3      | 3.80      |           |

Flow was the change magnitude on the plastic shape within paved mixed specimen that occurred due to the collapse load and it was expressed in units of length. The flow value was influenced by many factors, such as levels and viscosity of asphalt, temperature, gradation, and amount of density. The flow value that was too high indicated the plastic mixture and it was more capable in anticipating the deformation due to the load factors. Meanwhile, the flow that was too low can cause early cracking with low durability.

Based on Figure 6, it can be seen that there was a continuous and significant decrease in the flow value. The asphalt mixture without PET addition had the highest flow value of 3.37 mm. In details, the mixtures with 1% PET content decreased by 2.07% to 3.30 mm and the mixture of 1.5% decreased by 4.15%, so that the flow value became 3.23 mm. On the other hand, the 2% PET addition material obtained the biggest decrease, i.e. 8.01% and the flow value became 3.10 mm.

Referring to the Directorate General of Highways, the required flow value was 2 - 4 mm. According to the flow value data above, it can be concluded that the asphalt mixture with additional PET components of 1%, 1.5% and 2% had fulfilled the established requirements.

![Figure 6. Flow value](image-url)
3.6 Results of Stability testing

| Notation | Stability (kg) | Mean (kg) |
|----------|----------------|-----------|
| BK1      | 1963.82        |           |
| BK2      | 3972.80        | 2768.16   |
| BK3      | 2367.85        |           |
| 1P1      | 3281.51        |           |
| 1P2      | 3018.90        | 3060.42   |
| 1P3      | 2880.85        |           |
| 1,5P1    | 2978.59        |           |
| 1,5P2    | 3260.50        | 3061.26   |
| 1,5P3    | 2944.68        |           |
| 2P1      | 2880.85        |           |
| 2P2      | 3376.05        | 3088.43   |
| 2P3      | 3008.40        |           |

Stability was the ability of road pavement to receive traffic loads without any permanent changes in shape in the forms of flow waves and bleeding. The following is the stability comparison graph between the asphalt concrete mixture with and without addition of PET plastic material and carbide waste filler. Figure 7 showed that the stability value increased along with PET levels. It was influenced by PET plastic addition in the form of angular fibers and asphalt-covered aggregates tightly interlocked. The aggregate position was not easily shifted from its place when given some load. It indicated the increase of its stability.

In case of 0% PET content, it had the stability value of 2768.16 kg. The PET levels of 1%, 1.5%, and 2% had increased into 10.56%, 10.59%, and 11.57% respectively. For 1% PET content, it was 3060.42 kg. The highest stability value was in the addition of 2% PET content, i.e. 3088.43 kg. Moreover, for PET content of 1.5% was 3061.26 kg. These results indicated that all values in the mixture had met the minimum stability requirement of 1000 kg.

![Figure 7. Stability](image-url)
3.7 MQ (Marshall Quotient) testing results

Table 7. Data of MQ testing results

| Notation | MQ (kg/mm) | Mean (kg/mm) |
|----------|------------|--------------|
| BK1      | 467,58     |              |
| BK2      | 1528,00    | 904,37       |
| BK3      | 717,53     |              |
| 1P1      | 1025,47    |              |
| 1P2      | 1006,30    | 936,79       |
| 1P3      | 778,61     |              |
| 1.5P1    | 930,81     |              |
| 1.5P2    | 1018,91    | 947,35       |
| 1.5P3    | 892,33     |              |
| 2P1      | 1152,34    |              |
| 2P2      | 1125,35    | 1023,12      |
| 2P3      | 791,68     |              |

Figure 8 showed that MQ value with the addition of PET plastic tended to increase, since the flow value of the added specimen to PET plastic had a low value. The required specifications for a minimum MQ value were 250 kg/mm. For 0% PET content, the MQ value was 904.37 kg/mm, while the MQ value in PET content of 1%, 1.5%, and 2% increased. The value of MQ at asphalt mixture in each level increased into 3.58%, 4.75%, and 13.33% respectively. In details, the value of 1% PET content was 936.79 kg/mm, 1.5% PET content was 947.35 kg/mm, and 2% PET content was 1023.12 kg/mm. Based on Marshall study, the MQ value that met the requirements was the mixture of asphalt concrete in all PET levels.

Figure 8. MQ (Marshall Quotient)

4. Conclusions
Based on the results and discussion of the study, the additional levels of PET plastic and filler of carbide waste to the mixture of asphalt concrete affects the characteristic values of the Marshall. The higher the PET level, the more stable the value, VIM (Void In the Mix), VMA (Voids in Mineral Aggregate) and
MQ (Marshall Quotient). Meanwhile for density, VFA (Void Filled with Asphalt) and flow value has decreased.

The addition of PET plastic and carbide waste filler to the asphalt concrete mixture as a whole had met the requirements of the Directorate General of Highways of 2010, except for VIM and VFA values. VIM values that met the requirements were only for the addition of 0% and 1% PET levels. On the other hand, VFA value with PET content addition of 1.5% and 2% exceeded the required maximum limit of 65%.

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