The potential utilization of Polyethylene Terephthalate (PET) waste as fine aggregate replacement in asphalt mixture

A Meraudje¹, M I Ramli¹, M Pasra¹ and A A Amiruddin¹

¹Department of Civil Engineering, Faculty of Engineering, Universitas Hasanuddin, Makassar, Indonesia

E-mail: alberthmerauje@gmail.com

Abstract. One of the environmental issues in most regions of Indonesia is the large number of bottles made from poly-ethylene terephthalate (PET) deposited in domestic wastes and landfills. Due to the high volume of these bottles, more than 1 million m³ landfill spaces are needed for disposal every year. The purpose of this experimental study was to investigate the possibility of using PET waste in asphalt concrete mixes as fine aggregate replacement to reduce the environmental effects of PET disposal. Based on the test results, in terms of horizontal stress and indirect tensile stiffness modulus (ITSM) the use of waste PET waste increased the performance of the asphalt mixture prepared by the MBA.

1. Introduction

The re-use of wastes is important from a number of different points of view. It helps to save and sustain the natural resources which are not replenished; it decreases the pollution of the environment and it also helps to save and recycle energy in production processes. One of the important environmental issues in many locations in Indonesia is the large amount of poly-ethylene terephthalate (PET) wastes. The PET wastes are typically plastic beverage, margarine, shampoo and detergent bottles that are collected after use at many domestic waste sites and landfills.

It is now widely known that the use of polymers can improve the performance of asphalt mixtures, however the use of virgin polymers will increase the price of making asphalt mixtures. PET waste has a behavior as a polymer so that it can be used as an additive in the manufacture of asphalt mixture. In this concern, economically viable sustainable approach would be formed with the use of plastic waste such as waste PET as additive in the asphalt mixture fabrication. Several studies have shown that the asphalt mixture containing PET waste can deserve to be a practical reality [1].

In the southern Buton Island, Indonesia there are several regions where large amounts of natural bitumen arise on the ground and merge with sediments to form natural asphalt rocks. A section of this present study describes briefly several products generating from BRA. This research is part of a series of studies that aim to enhance the use of asphalt originating from BRA and one of them is MBA. In recent years, a number of BRA companies have succeeded in extracting bitumen from BRA. MBA is produced by mixing petroleum bitumen with bitumen extracted from BRA where petroleum bitumen obtained from the petroleum distillation process.

Indirect Tensile Stiffness Modulus (ITSM) value is one of the important characteristics of asphalt mixture design. ITSM value is a modulus of elasticity of asphalt mixture measured by using tensile
strength testing. [2], [3] The present research focuses on describing the synergistic effect of using MBa and PET waste on ITSM of asphalt concrete wearing course (ACWC) mixture.

2. Materials and methods

2.1. Types of bitumen derived from BNA
This section provides an outline of some types of production that derived from processing and developing BNA. In its development, BNA has been produced in several types, namely: Asphalt rock is the result of mining of BNA in rock boulder form with a size of about 10-30 cm. The utilization is limited because it requires mixing with flux oil and curing time after mixing with flux oil until the bitumen comes out of the rock boulder. Buton Natural Asphalt (BNA) is the result of processing BNA into a uniform granular from which still contains sediment and bitumen [4, 5, 6]. Modification is conducted to achieve uniform bitumen content in each grain. Liquid Asbuton is bitumen extracted from asphalt rock and still contains a number of minerals with an amount of about 30%. Almost pure bitumen which is the resulted of extraction from Buton natural asphalt containing minerals in a small amount of about 5% -10%. Modified Buton asphalt (MBA) is a mixture of petroleum bitumen and almost pure bitumen extracted from BNA.

2.2. Materials
The materials that have been utilized in this study are MBA, waste PET, river stone crushed, stone dust and filler. Table 1 shows the physical properties of MBA. Penetration value of 78.6 (unit: 0.1 mm) shows that BNA liquid was slightly harder than the pure petroleum bitumen with 60/70 penetration grade. The physical properties of river stone crushed was used as coarse aggregate stone dust as fine aggregate and particle pass sieve no. 200 as filler were available in Table 2, 3 and 4, respectively. The applied waste PET were used as the additive. Figure 1 shows the final crushed aggregate gradation used in this study.

| Table 1. Rheological properties of MBA. |
|----------------------------------------|----------|---------|
| Properties                              | Value    | Unit    |
| Penetration at 25°C                     | 78.6     | 0.1 mm  |
| Softening Point                         | 52.0     | °C      |
| Ductility                               | 114      | cm      |
| Flash Point                             | 280      | °C      |
| Density                                 | 1.12     |         |
| Loss on Heating TFOT                    | 0.30     | % wt    |
| Penetration after loss on heating       | 86.00    | 0.1 mm  |
Table 2. Properties of coarse aggregate.

| Properties                        | (Crushed stone) |
|-----------------------------------|-----------------|
|                                   | Diameter 5 - 10 (mm) | 10 - 20 (mm) |
| Water absorption, %               | 2.07            | 2.08          |
| Bulk specific gravity             | 2.62            | 2.63          |
| Saturated surface dry specific gravity | 2.68            | 2.68          |
| Apparent specific gravity         | 2.77            | 2.78          |
| Flakiness index, %                | 20.10           | 9.38          |
| Abrasion aggregate, %             | 25.72           | 24.36         |

Table 3. Properties of stone dust.

| Properties                        | Stone dust |
|-----------------------------------|------------|
| Water absorption, %               | 2.79       |
| Bulk specific gravity             | 2.54       |
| Saturated surface dry specific gravity | 2.51       |
| Apparent specific gravity         | 2.62       |
| Sand Equivalent, %                | 89.6       |
| Minimum size, mm                  | 0.075      |
| Maximum size, mm                  | 2.36       |

Table 4. Properties of filler (particle pass sieve no. 200).

| Water absorption, % | 2.28 |
|---------------------|------|
| Bulk specific gravity | 2.59 |
| Saturated surface dry specific gravity | 2.65 |
| Apparent specific gravity | 2.76 |

Figure 1. Final crushed aggregate gradation used in this study.

2.3. Asphalt concrete wearing course mixture preparation

Cylindrical specimens with diameter of 100 mm and height of 60 ± 5 mm are prepared using the standard Marshall hammer with 75 blows on each side at 6.25% bitumen content. In this study asphalt concrete mixture were prepared with 0.0, 1.0 and 2.0% waste PET as partial replacement of fine
aggregate. Table 5 shows the composition of mixtures without and with waste PET at 6.25% bitumen content for 1,200 grams.

Table 5. Composition of mixtures without and with waste PET at 6.25% bitumen content for 1,200 grams.

| No | Description                  | Unit | Waste PET content (%) |
|----|------------------------------|------|------------------------|
|    |                              |      | 0.0   | 1.0   | 2.0   |
| A  | MBA weight (6.25%)           | gr   | 75.00 |
| B  | Aggregate Combined Gradation | Aggregate weight according to sieve size |  
|    | Sieve size | % Passing | % Retained |  
| 1  | 3/4"        | 100.00 | 0.00 | gr | - | - | - |
| 2  | 1/2"        | 96.00  | 4.00 | gr | 45.03 | 43.91 | 42.78 |
| 3  | 3/8"        | 86.93  | 9.07 | gr | 102.03 | 100.91 | 99.78 |
| 4  | No. 4       | 63.90  | 23.03 | gr | 259.04 | 257.91 | 256.79 |
| 5  | No. 8       | 43.56  | 20.34 | gr | 228.79 | 227.67 | 226.54 |
| 6  | No. 16      | 28.62  | 14.94 | gr | 168.10 | 166.97 | 165.85 |
| 7  | No. 30      | 20.76  | 7.87  | gr | 88.50  | 87.38  | 86.25  |
| 8  | No. 50      | 15.60  | 5.16  | gr | 58.05  | 56.92  | 55.80  |
| 9  | No. 100     | 10.79  | 4.80  | gr | 54.02  | 52.89  | 51.77  |
| 10 | No. 200     | 8.43   | 2.37  | gr | 26.65  | 25.52  | 24.40  |
| 11 | PAN          | 0.00   | 8.43  | gr | 94.79  | 93.67  | 92.54  |
| 12 | Waste PET   | -      | -     | gr | -      | 11.25  | 22.50  |
|    | Total       | 100.00 | gr    | 1,125 | 1,125 | 1,125 |

C Sample weight | gr | 1,200 | 1,200 | 1,200 |

2.4. Indirect Tensile Stiffness Modulus (ITSM)

ITSM resilient modulus is the comparison between the applied peak deviator stress and the related elastic axial strain of material that undergoes cyclic axle loads. The resilient modulus of asphalt mixtures was obtained from ITSM test. This test was conducted according to standard AS2891.13.1-1995 [21]. Table 4 presents the test conditions. Fig. 2 shows the setup of ITSM specimen. The determination of the resilient modulus was purposed to record the effect on the stiffness modulus of asphalt mixtures of using three percentages (0.0, 1.0 and 2.0%) of waste PET in one MBA content.
Figure 2. The setup of ITSM specimen.

| Parameters                        | Value            |
|-----------------------------------|------------------|
| Test temperature, °C              | 25 ± 0.5         |
| Rise time $f_m$ (10% to 90%), ms  | 40 ± 5           |
| Pulse repetition period (10% to 10%, ms) | 3000 ± 5       |
| Recovered horizontal strain, $\mu\varepsilon$ | 50 ± 20 |
| Air voids, %                      | 5 ± 0.5          |
| Content of waste plastic, %       | 0.0, 1.0 and 2.0%|

### 3. Results and discussion

Figure 3 shows the relationship between horizontal stress and the percentage of waste PET. With the addition of 1.0% and 2.0% PET plastic waste, the horizontal stress response was reduced where the horizontal stress of mixture without PET, with PET 1.0 and 2.0% was 140 kPa, 87 kPa and 37 kPa, respectively.
Figure 3. The relationship between horizontal stress and the percentage of waste PET.

Table 7. Void in Mix value versus BGA 50/30 content

| Mixture                      | Resilient Modulus (Mr) |
|------------------------------|------------------------|
| AC-WC without waste PET      | 1470 MPa               |
| AC-WC with waste PET 1.0%    | 1697 MPa               |
| AC-WC with waste PET 2.0%    | 3024 MPa               |

Table 7 shows the relationship between horizontal stress and resilient modulus values. With the addition of 1.0% and 2.0% PET plastic waste, the resilient modulus increases where the AC-WC resilient modulus without PET, with PET 1.0 and 2.0% was 1470 MPa, 1697 MPa and 3024 MPa, respectively.

4. Concluding Remarks
Based on the test results, it can be seen that the use of PET waste increases the performance of the asphalt mixture prepared by the MBA. The condition of PET in the form of semi-crystalline rendered the mixture prepared with an MBA which leads to higher performance related to horizontal stress and ITSM.

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