Effect of coconut-shell ash as filler and plastic bottle as substitution of porous asphalt mixture

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Abstract. Generally, porous asphalt mixtures are having low stability and highly dependent on the quality of asphalt as an aggregate binder, so the innovation of using additive needs to be examined to produce high quality asphalt. In this study, the additive used in asphalt mixtures is plastic bottle waste (Polyethylene Terephthalate/PET) and the use of coconut-shell ash (CS) as filler. This study aims to find out the influence of using PET waste and CS in asphalt porous mixtures which meets its parameter of Cantabro Loss (CL), Asphalt Flow Down (AFD), Marshall and permeability test on 60/70 asphalt penetration. Its benefit is to discover the influence of adding PET and ATK. In this research, the variation of asphalt content was made to obtain Optimum Asphalt Content (OAC) of 4.5%, 5.0%, and 6.0%. Australian Asphalt Pavement Association (AAPA) method was used to determine OAC including CL, AFD, and Void in Mix (WIM) test. After OAC was determined, OAC specimen with the variation of 0%, 2%, 4% and 6% PET substitute on asphalt weight, and the use of 50% combination of CS and portland cement from the total weight of filler were made. At OAC value of 5.74%, it is obtained that the value of CL, AFD, Marshall and permeability which meet the AAPA specifications is in the addition of 2% and 4% PET in PA mixture.

1. Introduction

Roads infrastructure is to connect one area to another and also to improve the process of economic development in the community. Road damage generally occurs due to existency of puddle on road surface from high rainfall, which reduces rainwater infiltration and accelerates the damage. Porous asphalt is one of pavement type that is developed on the surface layer.

Porous Asphalt (PA) is strongly related to the behavior and properties of asphalt mixtures that use aggregate gradations with a number of coarse fractions above 85% of the total weight of the mixture, which is resulting on porous asphalt structure. The existing cavities provide the ability to drain water both vertically and horizontally so that it will keep the surface layer dry, mean while large cavities can cause a decrease of characteristic value on PA mixture [1, 2]. Generally, PA mixture has low stability and is highly dependent on the quality of asphalt as an aggregate binder, so modified asphalt is needed to produce high quality asphalt [3].

Modified asphalt is an asphalt made by mixing hard asphalt with additive material, which is intended to improve the physical properties of asphalt. One alternative to deal with the rare of modified asphalt is to use other materials as an additive materials including the utilization of plastic bottle waste (Polyethylene Terephthalate / PET) for asphalt substitution material [4, 5] and Coconut Shell Ash (CA) as filler substitution material in PA mixture so that asphalt mixture characteristics is found out later. This research aims to find out the influence of using PET waste and CS ash on PA mixture
which meet CL, AFD, VIM and permeability coefficient on 60/70 asphalt penetration which is based on AAPA spesification 2014 [6].

2. Materials and methodology

2.1. Material selection

2.1.1. Aggregate
Material used in this investigation is coarse and fine aggregate which come from stone crusher located in Seulimum, Aceh Besar Sub-District. Porous asphalt gradation (open graded) is used as shown in Table 1. The results of physical properties of tested aggregates are given in Table 2.

Table 1. Gradation of porous asphalt

| Sieve Size (mm) | Specification passing range (%) | Used Passing (%) |
|----------------|---------------------------------|------------------|
| 19.0           | 100                             | 100              |
| 13.2           | 85 – 100                        | 92.5             |
| 9.5            | 45 – 70                         | 57.5             |
| 4.75           | 10 – 25                         | 17.5             |
| 2.36           | 7 – 15                          | 11               |
| 1.18           | 6 – 12                          | 9                |
| 0.6            | 5 – 10                          | 7.5              |
| 0.3            | 4 – 8                           | 6                |
| 0.15           | 3 – 7                           | 5                |
| 0.075          | 2 – 5                           | 3.5              |

Table 2. Physical properties of aggregate

| No. | Physical Properties | Unit     | Value | Requirement |
|-----|---------------------|----------|-------|-------------|
| 1   | Specific gravity    | gr/cm³   | 2.78  | Min. 2.5    |
| 2   | Absorption          | %        | 1.12  | Max. 2     |
| 3   | Unit weight         | Kg/dm³   | 1.67  | Min. 1     |
| 4   | Hardness            | %        | 8.94  | Max. 30    |
| 5   | Abrasion            | %        | 15.02 | Max. 40    |
| 6   | Flakiness index     | %        | 17.42 | Max. 25    |
| 7   | Elongated index     | %        | 15.43 | Max. 25    |

2.1.2. Asphalt Binder
The conventional 60/70 penetration grade bitumen was used for producing the tested PA mixtures. The main characteristics of the used bitumen are summarized in Table 3.

Table 3. Characteristics of 60/70 conventional bituminous binder

| No. | Test           | Unit | Value | Requirement |
|-----|----------------|------|-------|-------------|
| 1   | Penetration    | mm   | 64    | 60-70       |
| 2   | Ductility      | cm   | 120   | Min. 100    |
| 3   | Softening Point| °C   | 49    | Min. 48     |

2.1.3. Plastic Bottle (PET)
PET waste is obtained from PET bottle. PET is one of polyester material often used as a packaging in beverage industry. PET is easy handled polymer and strong, durable, low gas permeability, thermally and chemically stable [7]. Table 4 shown the physical properties of PET.

Table 4. Properties of plastic bottle [4]

| No. | Test             | Unit    | Value |
|-----|------------------|---------|-------|
| 1   | Density          | g/cm³   | 1.35  |
| 2   | Tensile Strength | psi     | 11,500|
| 3   | Water absorption | %       | 0.1   |
| 4   | Approx. melting temperature | °C | 250 |
2.1.4. Coconut-shell Ash (CA)
Active carbon is a material that has a large amount of cavities which has a function to absorb everything through it. One of them is an activated carbon material derived from animals, plants, or minerals containing carbon, among others: CA, hardwoods, palm oil, some are from coal, bones, sugar cane ash, sawdust and others [8]. Coconut-shell ash is an ash in the form of soil or mineral materials such as silica, which is the residual combustion of charcoal that has become ash, with black to gray colour, usually tasteless and odorless.

3. Experimental plan
This experimental research was made by testing the characteristic of PA with certain proportion variation of PET on 60/70 asphalt penetration using 50% CA as filler. The step in this research is preparing material and tools, examining physical properties of aggregates and asphalt, and sieve analysis. As it meets the specified requirement, then the experiment can be continued to specimens manufacturing.

3.1. Sample Preparation
Australian Asphalt Pavement Association (AAPA) 2004, determined that the used asphalt content is at 4.5% - 6% and with 2 x 50 collisions for each specimens test (50 collisions on each surface of specimens). After OAC is obtained, PET is added with the variation of 0%, 2%, 4%, and 6%. PET bottle is substituted in PA mix. Bottle was cutted into small pieces. CA preparation was performed by taking the weighting charcoal sample in order to obtain constant mass around 1 gram and then the sample is then heated for 3 hours at 900°C. After finishing, the sample is then cooled and weighed again in order to obtain ash content.

4. Results and discussion
In this study, the characteristic of PA is found by performing test including Cantabro Loss, Asphalt Flow Down, Marshal and permeability. The result of CL, AFD and VIM with the variation of asphalt content to determine OAC can be seen in Table 5. It is found in this research that 5.74% is an optimum asphalt content.

| Table 5. Summary of test result without PET (Determination of OAC) |
|---------------------------------------------------------------|
| **Test** | **Unit** | **Asphalt Content (%)** | **Requirement** |
|----------|----------|------------------------|----------------|
| Asphalt Flow Down | % | 4.5 | 5.0 | 5.5 | 6.0 | |
| Void in Mix | % | 23.03 | 21.57 | 19.81 | 19.06 | 18-25 |
| Cantabro Loss | % | 30.40 | 26.85 | 19.86 | 17.89 | Mak. 20 |
| Permeabilitas | cm/s | 0.18 | 0.19 | 0.21 | 0.24 | 0.1-0.5 |

4.1. Effect of PET substitution to asphalt flow down
Figure 1 illustrates the higher PET percentage cause the decrease on AFD value, excluding variation of 6% PET which increases. This is due to the increasing levels of PET in asphalt which causes smaller level of separation of asphalt in the mixture.

![Figure 1. Asphalt flow down value with the different PET contents](image)
4.2. Effect of PET substitution to void in mix
From the test result, it can be concluded that VIM value increases for all variation both for with or without variations of PET + 50% ATK. The biggest value is on the variation of 6% PET which is 22.95%. Cracking can be risen by many air void formed as the result of asphalt binders that are not perfectly coated, while asphalt bleeding and rutting may be induced by low air voids. [9]. Furthermore, when PET is used in a mixture, it seems to reduce its compact ability, where this condition allows a higher air void value (Figure 2).

![Figure 2. Asphalt void in the mix value with the different PET contents](image)

4.3. Effect of PET substitution to Cantabro loss
Based on the cantabro loss test results, Figure 3 shows that the highest the percentage of PET + 50% CA substitution. The highest value of 26.18% is found at variation of 6% PET and the lowest value is 15.21 % at variation of 0% PET. The cantabro loss value specification as implied by AAPA (2004) is 20 maximum, the higher the PET value, the weaker the resistance to destruction. However only the mixture with 2% PET content that satisfy the specification of lower than 20.

![Figure 3. Cantabro loss in the mix value with the different PET contents](image)

4.4. Effect of PET substitution to permeability
The results of the permeability test in Figure 4 show the water flow rate is strongly influenced by the number of continuous cavities present in the mixture. This permeability value is caused by the formation of continuous cavities in the mixture which causes the flow of water from the surface vertically to the bottom is faster. It is examined that for all variations of PET content, the permeability testing value meets the specifications, which are 0.1-0.5 cm/ s.
4.5. *Marshal stability and flow*
Figure 5 illustrates the Marshall Stability and Flow value versus PET content for optimum asphalt content. From the results of stability test, on porous asphalt without or with PET + 50% CA, it is shown that there was an incremental of the stability value, but there was a decrease in the variation of the addition of 6% PET. An increase value of stability occurs in variations of 0%, 2% and 4% PET. It increases from 5.17 kN at the variation of 2% PET to 5.46 kN at the variation of 4% PET. However it decreases at the variation of 6% PET to 4.58 kN. The best stability value is at variation of 4% PET with control using 0% variation (without PET mixture). Polymer can increase stability in hot mix asphalt and develop connection between material in the mixture [9, 10]. Furthermore, in the flow test for variations of PET + 50% CA substitution, the value of each PET addition decreases except for variation of 6% PET. However, a high percentage of PET causes the flow to increase while the stability decreases.

![Figure 5: Relationship between stability and flow at different PET contents](image)

4.6. *Marshal Quotient*
Marshall Quotient (MQ) values is calculated in order to evaluate specimen deformation as it is an indicator to resist deformation of the bituminous mixture [11, 12]. Figure 6 shows the results of the MQ (Marshall Quotient) test of PA on either with or without PET shows the increasing MQ values. The increase in MQ value occurs in variations of 2% and 4% of PET. At the level of 2% PET, it increases from 135.42 kg to 141.63 kg, at the level of 4% it increases to 154.84 kg, while at the variation of 6% PET experienced a decrease of 124.34 kg. The best MQ values are in the 4% variation with controls using 0% content without PET mixture. The higher the MQ value the asphalt will become stiff, easy to crack but has high stability. Vice versa, asphalt will be more susceptible to change in shape due to daily traffic load.

![Figure 6: MQ values vs. PET content](image)
5. Conclusion

There are some summary can be drawned for this experimental results. Therefore, it can be concluded that: First, adding PET to the mixture decreases the AFD, however it experiences an increasing at the variation of 6% PET. The highest VIM values is at 4% PET addition. Second, the increasing variation of PET addition causes greater value of CL, in other words the resistance of the mixture to the release of granules becomes smaller. Third, for a particular PET content, the permeability of the porous mix increases as the amount of PET increases. Fourth, as content of PET + 50% CA increases into the porous asphalt mixture, Marshall Stability also increases, but then decreases after 4% of PET addition. However, the opposite condition occurs in Marshall Flow where the use of PET + 50% CA causes a decrease in value at the beginning followed by an increase when the use of PET increases into the mixture. For last, the incremental of PET content + 50% CA cause the increase of stiffness level in the mixture, which lead an increase in resistance to permanent deformation at the MQ value.

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Figure 6. Marshall Quotient in the mix value with the different PET contents