The effect of wood ash and styrofoam on the characteristics of AC-WC mixture

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Abstract. In this study, two types of substitutions, wood ash, and styrofoam, were used in asphalt concrete. The substitution of wood ash and styrofoam for asphalt concrete’s filler is expected to enrich the variations of the asphalt concrete material as well as to reduce the existing industrial waste. This study objective is to determine the effect of the asphalt mixture, which filler was substituted with the wood ash, on the Marshall test results. The initial stage of the research is to examine the physical properties of the asphalt and aggregate. Then, the optimum asphalt content (OAC) of the asphalt mixture was estimated. Then, the asphalt mixture’s filler was substituted with the wood ash and the asphalt material was substituted with the styrofoam. The result of this study is the best combination of the wood ash in asphalt mixture, which is 25% of the total filler, and the best combination of the styrofoam in asphalt mixture, which is 9% of the total asphalt content. With these best combinations of the wood ash and the styrofoam, the obtained Marshall stability of the asphalt concrete was 1,249.01 kg, which fulfills the ‘2018 Bina Marga’ requirement.

1. Introduction

Asphalt, as a binding material of paved mixtures in the flexible pavement, has a significant influence on the service life of the pavement layer. Therefore, it is necessary to improve the quality of construction of the transportation infrastructure that is environmentally friendly, inexpensive, and durable. One of the alternatives is the modified asphalt material. Modifying asphalt material can also be an alternative solution for the waste by using the waste polymer materials that are difficult to decompose in the soil. One of the polystyrene wastes is styrofoam that functions as an unusable food container. Putri [1] stated that using styrofoam waste or foamed plastic as an additive for asphalt forms a new binding material for road construction pavement due to its properties, which is thermoplastic solid at room temperature and liquid at higher temperatures. According to Listiani [2], besides the technical advantages, the utilization of polystyrene waste is also beneficial to Indonesia’s environment and economy. Also, modified asphalt has high viscosity at low temperatures and low viscosity at high temperatures, which is favorable for construction [3].

Most fillers have a high price. For this reason, innovation is needed by using substitute materials that are more profitable and efficient in an asphalt mixture and also accessible but lessens in the utilization, like
wood ash. In this study, wood ash was used as a filler substitute for portland cement. Wood ash waste has the potential to be used as a filler substitution for the asphalt concrete wearing course (AC-WC) because this material passed No. 200 filter, which is the requirement of filler material. Hossain [4] stated that wood ash is suitable for polymer asphalt filler because of its cost-effectiveness, low density, high rigidity, high strength, and low price.

2. Literature review

2.1. Aggregate
According to the general specifications [5], the coarse aggregate must retain the No. 4 sieve (4.75 mm) and the fine aggregates, which must be composed of sand or the product from crushed stones, must pass the No. 4 sieve (4.75 mm) and retain the No. 200 filter (0.075 mm).

2.2. Fillers
The filler is a non-plastic material with a minimum of 75% of the weight passing the No. 200 filter (0.075 mm). Filler lies between the coarse aggregate cavity and fine aggregate to reduce the size of the cavity, increase the density, and increase the stability of the asphalt mixture. Filler can be limestone dust, stone ash, fly ash, or other materials. Filler must be in a state dry with a maximum water content of 1% [6]. The requirements for fillers are shown in the following table 1.

Table 1. Requirements for fillers [5].

| Testing                        | Standard            | Value         |
|-------------------------------|---------------------|---------------|
| Pass the No. 200 filter       | SNI 03-4428-1997   | Min. 75 %     |
| Free of organic ingredients   | SNI 03-4428-1997   | Maks. 4 %     |
| Filler specific gravity       | SNI 0013 - 81      | 2.5 gr/cm²    |

2.2.1. Wood ash. Ash is the leftover material from the wood-burning process. Sulaiman [7] stated that wood ash could contain much silica if it is burned at high temperatures reaching 500-700 °C.
2.3. Asphalt
Asphalt or bitumen is a brownish-black and viscoelastic material. It will soften and melt if it is heated up and hardens if the temperature decreases. This viscoelastic character makes asphalt envelopes the aggregates and make the aggregates durable [8]. Sukirman [9] stated that asphalt is the material which is solid at room temperature. The amount of asphalt in the pavement mixture ranges from 4-10% by the mixture weight or 10-15% by the volume.

2.3.1. Modified asphalt. Modified asphalt is made by mixing concrete asphalt with additional material. Modified asphalt is often called polymer bitumen (plastomer and elastomer). The percentage of polymer addition into the concrete asphalt mixtures must be determined by laboratory testing because adding sufficient material can improve the asphalt rheological properties such as penetration, thickness, softening point, and concrete asphalt elasticity, while the excessive additions will generate the adverse effect. The improvement of asphalt rheological properties is generally influenced by the content of the polymer, bitumen grade, and a particular type of polymer [10].

2.3.2. Styrofoam. Styrofoam is one of the types of polymer that is thermoplastic: it will soften if it is heated and harden when it becomes cold. According to Billmeyer in Giri [11], styrofoam is a compatible material in terms of mechanism and temperature, but it is somewhat fragile and soft at temperatures below 100 °C. According to Crawford in Giri [11], styrofoam has a density of up to 1,050 kg/m^3, a tensile strength of up to 40 MN/m^2, a flexural modulus of up to 3 GN/m^2, shear modulus of up to 0.99 GN/m^2, and the Poisson ratio of up to 0.33.

![Figure 2. a) Styrofoam as a food container: b) Styrofoam after being cut into pieces.](image)

3. Methods and analysis

3.1. Aggregate testing
The aggregate is the crushed gravel, which is classified as fine aggregate. It is produced by PT. Dana Dinamika Persada, located in Leupung Baleu, Cot Glie, Aceh Besar, Aceh. The testing on the aggregate physical properties includes testing on asphalt consistency (penetration testing, ductility), testing on temperature sensitivity (softening point), and testing on asphalt specific gravity.
3.2. Preparation of fillers
In this study, the filler was wood ash and portland cement. The wood ash is generally in the form of powder and is the left of material from the wood-burning. The wood ash is the waste wood from the sawmill and the furniture making. Formerly, the wood is burned for approximately 30 minutes to 1 hour. Wood ash is prepared using a burning procedure in a laboratory furnace under continuous air supply. The combustion temperature is set at 600 °C as suggested by ASTM EN 870-82. Xue [12] stated that generally, 6-10% of the burned wood produces ash. The obtained ash, according to Xue, then pounded until creating a homogeneous size that can pass the No. 200 filter (0.075 mm). Wood ash is used because the results of the combustion consist of 85% of silica, which is a compound that can react to water and form new substances that are adhesive to rocks. In other words, wood ash properties, in this case, are similar to portland cement.

The density of wood ash was 2.9 gr/cm³, which is based on Cahya's research [13]. Otoko [14] mentions some of the chemical properties contained in wood ash that are shown in the following table 2.

| Element | Content (%) |
|---------|-------------|
| Fe2O2   | 1.70%       |
| Al2O3   | 2.70%       |
| SiO2    | 85%         |
| MgO     | 0.25%       |
| CaO     | 3.50%       |

3.3. Selection of styrofoam waste
The utilization of waste as an alternative material is very beneficial for the environment, especially for the waste that is difficult to decompose like styrofoam or polystyrene. Styrofoam has to be treated before mixed with other additives. The initial treatment of styrofoam waste was carrying it out through heating and pressing it by using the hydraulic press at a temperature of 170°C and a pressure of 170 kg/cm² for 13 minutes. The purpose of this treatment is to remove the pores of styrofoam. After the pressing process, the process was continued with enumeration or cutting the styrofoam into a maximum of 2 x 2 mm² to facilitate the dissolution process of the aggregate mixture. Then, the object was put into the hot asphalt with the appropriate temperature and then stirred at high speed. Then, the hot aggregate is added and stirred again until the mix becomes homogeneous. When all plastic waste is dissolved into the aggregates and the hot asphalt, subsequently, the aggregate mixture can be used for concrete asphalt mixture.

3.4. Determination of asphalt content variations
Asphalt content was determined based on the initial estimation of asphalt content, called the medium asphalt content. The medium asphalt content is calculated using the following formula:

\[ P_b = 0.035 \times (\% \text{CA}) + 0.045 \times (\% \text{FA}) + 0.18 \times (\% \text{filler}) + K \]

In this study, based on designed aggregate gradation, CA = 36.50%, FA = 58.5%, filler = 6.2% and the selected constant value is 0.5. The medium asphalt content resulted from the formula is 5.5%. Then, the samples of asphalt concrete wearing course (AC-WC) mixture have to contain the asphalt content of 4.5%, 5%, 5.5%, 6%, or 6.5%.
3.5. The design of concrete asphalt mixture with the selected aggregate gradation

The gradation used in this study is continuous gradation based on the middle value of the technical specifications [5].

3.6. Producing and testing the test items

The test items of AC-WC mixture in this study consisted of the following three groups:
1. Test items contain the optimum asphalt content (OAC);
2. Test items contain the filler composed of 25% wood ash and 75% Portland cement and the styrofoam which is 7%, 9% and 11% of the wet weight of OAC;
3. Test items contain the best combination of wood ash and styrofoam based on the previous tests and tested for durability at 30 minutes and 24 hours immersion.

After the producing process of the test items, subsequently, the procedure was continued with Marshall testing. The total of the test items in this study is presented in table 3.

Table 3. Recapitulation of total test items.

| No. | Description                                      | Total |
|-----|--------------------------------------------------|-------|
| 1   | Test items to obtain OAC                         | 15    |
| 2   | Test items with the combination of wood ash and styrofoam | 27    |
| 3   | Durability test at 30 minutes and 24 hours immersion | 6     |
|     | **Total**                                       | **48**|

4. Results and discussion

4.1. Test results

The results of properties examinations of the aggregates obtained from Leupung Baleu, Kuta Cot, Aceh Besar, Aceh, are presented in table 4.

Table 4. Physical properties of coarse aggregates.

| Physical properties examined | Standard               | Results | Unit | Specification of Bina Marga, 2018 |
|------------------------------|------------------------|---------|------|-----------------------------------|
| Time-worn                    | SNI 2417-2008          | 9.63    | %    | Max. 40%                          |
| Tin Index                    | ASTM D-4791            | 27.35   | %    | Max. 10%                          |
| Oval Index                   | ASTM D-4791            | 20.96   | %    | Max. 10%                          |
| Specific Gravity             | SNI 1969-2008          | 2.8     | -    | Min. 2.5                          |
| Absorption                   | SNI 1969-2008          | 0.263   | %    | Max. 3%                           |
| Weight of contents           | AASHTO T-19-74         | 1.625   | Kg/dm| Min. 1%                           |
| Impact                       | SNI 03-4426-1997       | 7.71    | %    | Max. 30%                          |

Based on the results, the aggregate physical properties have met the requirements, except for the elongation index value that is above 10%. However, based on Bina Marga specifications [15], there is the requirement stated that if there is nonconformity for the elongation index, the value can be tolerated if the aggregates fulfill all other requirements, primarily the result of abrasion testing using Los Angeles machines. Besides these tests, the results of impact testing have met the requirements.
Table 5. Physical properties of fine aggregates.

| Testing        | Standard       | Results | Unit     | Specification of Bina Marga 2018 |
|----------------|----------------|---------|----------|----------------------------------|
| Specific Gravity | SNI 03-1970-1990 | 2.8     | gr/cm³   | Min. 2.5                         |
| Absorption     | SNI 03-1970-1990 | 0.263   | %        | Max. 3%                          |

Table 6. Asphalt penetration 60/70 physical properties.

| No. | Physical Properties of Asphalt | Standard       | Unit | Specification of Bina Marga 2018 |
|-----|---------------------------------|----------------|------|----------------------------------|
| 1   | Specific Gravity (25 °C)        | SNI 2441-2011  | 1.029| ≥ 1.0                            |
| 2   | Penetration (25 °C; 5 s; 0,1 mm; 100 g) | SNI 06-2456-1991 | 65   | Min. 60-70                       |
| 3   | Ductility (25 °C; 5 cm/sec)    | SNI 2432-2011  | 120  | ≥ 100                            |
| 4   | The soft spot; °C              | SNI 2432-2011  | 49   | ≥ 49                             |

Table 7. Physical properties of asphalt penetration 60/70 containing styrofoam.

| No. | Physical Properties of Asphalt | Unit | Styrofoam Content | Specification of Bina Marga, 2018 |
|-----|---------------------------------|------|-------------------|----------------------------------|
| 1   | Specific Gravity                | -    | 1.035             | 1.04                             | 1.05                             | ≥ 1.0                            |
| 2   | Penetration (0.1 mm)            |      | 58.6              | 57.8                             | 55.8                             | Min. 60-70                       |
| 3   | The Soft Spot                   | °C   | 48.5              | 49                               | 49.5                             | ≥ 49                             |
| 4   | Ductility                       | cm   | 120               | 120                              | 120                              | ≥ 100                            |

The values of specific gravity, penetration, softening point and ductility have met the requirements of General Specifications [5].

4.2. Marshall test results

Based on the Marshall test results, which is shown in table 8, the optimum asphalt content (OAC) is 6.05%. However, the asphalt content used to examine the properties of asphalt concrete containing wood ash and styrofoam was obtained by adding and reducing the OAC value (6.05%) with two somewhat equal values. As a result, the asphalt contents used in the test of asphalt concrete containing wood ash and styrofoam were 5.60%, 6.05%, and 6.50%.

Table 8. Recapitulation of Marshall test results with variations in bitumen content.

| No | Mix Characteristics | 4.50 | 5.00 | 5.50 | 6.00 | 6.50 | Specification of Bina Marga, 2018 |
|----|---------------------|------|------|------|------|------|----------------------------------|
| 1  | VIM (%)             | 6.88 | 6.82 | 4.66 | 4.30 | 4.07 | 3 – 5                            |
| 2  | VMA (%)             | 17.55| 18.58| 17.79| 18.56| 19.44| Min. 15                          |
| 3  | VFA (%)             | 60.94| 63.41| 74.39| 76.95| 79.16| Min. 65                          |
| 4  | Stability (Kg)      | 1,321.72| 1,071.68| 1,108.75| 929.05| 1,002.61| Min. 800                       |
| 5  | Flow (mm)           | 3.93 | 3.90 | 4.00 | 3.83 | 3.73 | 2 – 4                            |
4.3. Results of examination of wood ash

Table 9. Marshall test results for asphalt concrete containing filler of 25% wood ash and 75% portland cement.

| No | Mix Characteristics | Asphalt content (%) | Specification of Bina Marga, 2018 |
|----|---------------------|---------------------|-----------------------------------|
|    |                     | 5.60                | 6.05                | 6.50                |                                    |
| 1  | VIM (%)             | 4.87                | 4.39                | 3.86                | 3 - 5                             |
| 2  | VMA (%)             | 18.17               | 18.72               | 19.24               | Min. 15                           |
| 3  | VFA (%)             | 73.21               | 76.57               | 79.99               | Min. 65                           |
| 4  | Stability (Kg)      | 1,047.95            | 1,129.51            | 1,119.14            | Min. 1,000                        |
| 5  | Flow (mm)           | 3.33                | 3.87                | 3.93                | 2 - 4                             |

4.4. Styrofoam examination results

Table 10. Marshall test results for asphalt concrete containing filler of 25% wood ash and 75% portland cement and containing 7% styrofoam in the asphalt.

| No | Mix Characteristics | Asphalt Content (%) | Specification of Bina Marga, 2018 |
|----|---------------------|---------------------|-----------------------------------|
|    |                     | 5.60                | 6.05                | 6.50                |                                    |
| 1  | VIM (%)             | 6.28                | 5.29                | 4.57                | 3 - 5                             |
| 2  | VMA (%)             | 19.33               | 19.43               | 19.78               | Min. 15                           |
| 3  | VFA (%)             | 67.51               | 72.79               | 76.98               | Min. 65                           |
| 4  | Stability (Kg)      | 1,173.32            | 1,052.41            | 1,075.54            | Min. 1,000                        |
| 5  | Flow (mm)           | 3.23                | 4.43                | 4.30                | 2 - 4                             |

Table 11. Marshall test results for asphalt concrete containing filler of 25% wood ash and 75% portland cement and containing 9% styrofoam in the asphalt.

| No | Mix Characteristics | Asphalt Content (%) | Specification of Bina Marga, 2018 |
|----|---------------------|---------------------|-----------------------------------|
|    |                     | 5.60                | 6.05                | 6.50                |                                    |
| 1  | VIM (%)             | 5.66                | 5.93                | 4.35                | 3 - 5                             |
| 2  | VMA (%)             | 18.71               | 19.89               | 19.49               | Min. 15                           |
| 3  | VFA (%)             | 69.73               | 70.18               | 77.75               | Min. 65                           |
| 4  | Stability (Kg)      | 1,103.02            | 1,175.76            | 1,249.01            | Min. 1,000                        |
| 5  | Kelelehan (mm)      | 3.50                | 3.20                | 3.13                | 2 - 4                             |

Table 12. Marshall test results for asphalt concrete containing filler of 25% wood ash and 75% portland cement and containing 11% styrofoam in the asphalt.

| No | Mix Characteristics | Asphalt Content (%) | Specification of Bina Marga, 2018 |
|----|---------------------|---------------------|-----------------------------------|
|    |                     | 5.60                | 6.05                | 6.50                |                                    |
| 1  | VIM (%)             | 5.73                | 5.47                | 6.15                | 3 - 5                             |
| 2  | VMA (%)             | 18.64               | 19.36               | 20.87               | Min. 15                           |
| 3  | VFA (%)             | 69.26               | 71.73               | 70.51               | Min. 65                           |
| 4  | Stability (Kg)      | 1,079.39            | 1,144.93            | 1,101.14            | Min. 1,000                        |
| 5  | Flow (mm)           | 3.63                | 3.83                | 3.70                | 2 - 4                             |
Based on the results, the best mix was asphalt concrete containing 6.5% asphalt content, 9% of which was styrofoam, and filler composed of 25% of wood ash and 75% of portland cement. The stability value of this asphalt concrete was 1,249.01 Kg, which meets the requirement of the General Specifications [5].

4.5. Results of durability value
The Marshall immersion test for 30 minutes and 24 hours at 60 °C was carried out to obtain the durability value of the asphalt mixture.

![Graph of Value of Durability Against Variations in Wood Powder Ash Filler with Styrofoam](image)

**Figure 3.** Durability testing charts.

Based on the result, the durability of asphalt concrete containing filler composed of 25% wood ash and 75% portland cement and containing 6.05% asphalt did not meet the requirement. The obtained value is 81.76%, while the required value is 90% or higher. It happens because wood ash fillers cannot fill the pores of the mixture. This fact can be observed from the asphalt concrete VIM which tends to be high. On the other hand, the asphalt concrete containing asphalt composed of 9% styrofoam and containing filler composed of 25% wood ash and 75% portland cement has the durability value of 96.51%, which meets the specification.

4.6. Discussion
The use of wood ash as a substitute for filler and styrofoam as a substitute for asphalt, at the best composition, can affect the value of Marshall properties, which are VIM, VMA, VFA, stability, and flow. VIM values tend to increase with the increasing content of styrofoam in asphalt. This fact happens because the asphalt gets thicker and harder. The value of VMA can also indicate the thickness of the asphalt blanket on the aggregate. The VMA value is influenced by the asphalt content that envelopes the aggregate; a high asphalt content will form a thick blanket of aggregate resulting in larger pores between aggregates. The value of VFA increases with the increase of asphalt content and styrofoam content. The increase of VFA is because of the increasing amount of filled pores by the addition of asphalt content and styrofoam content. Adding styrofoam into the mixture can increase the stability of the AC-WC mixture; as a result, the shear resistance at high temperatures and damage prevention improves. High stability increases the ability of AC-WC mixtures to carry vehicle loads, while the increase of flow values increases the flexibility of the AC-WC mixture. It induces the favorable durability and flexibility of AC-WC. However, substituting wood ash
to asphalt concrete’s filler without adding the styrofoam into the asphalt does not improve the asphalt concrete durability and stability; conversely, substituting wood ash to asphalt concrete’s filler and styrofoam to asphalt does improve the asphalt concrete durability and stability.

5. Conclusion and suggestion

5.1. Conclusion
1. Optimum asphalt content (OAC) is varied into three: 5.60%, 6.05%, and 6.50%. Based on the Marshall testing evaluation, the final OAC was 6.05%.
2. The best percentage of substituted materials for asphalt concrete’s filler is 25% of wood ash and 75% of portland cement, performed at 6.05% of asphalt content.
3. The asphalt concrete stability increases by substituting the wood ash to filler and styrofoam to asphalt. The highest stability, obtained at 6.50% of asphalt content and 9% of styrofoam, is 1,249.01 kg, while the lowest stability, obtained at 6.05% of asphalt content and 7% of styrofoam, is 1,052.41 kg.
4. The durability of asphalt concrete substituted by wood ash is 81.76%. The value does not meet the required value, which is at least 90%, as stated in the 2018 fourth revision General Specifications of Bina Marga. Whereas, the durability of asphalt concrete substituted by wood ash and styrofoam is 96.51% and fulfill the requirement.
5. Wood ash as filler substitution and styrofoam as asphalt substitution in asphalt mixture affect the increase of stability and flow; styrofoam substitution in durability testing affects durability and stability values.

5.2. Suggestion
1. For future studies, other types of plastic with a different variation percentage should be used;
2. The asphalt mixture durability within 30 minutes and 24 hours immersion has a high VIM value; thus, in the future, porous asphalt should be used because styrofoam is appropriate for porous asphalt.

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