The use of Sabang mountain rocks and substitution of LDPE in the AC-WC mixture with dry method

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Abstract. The aggregate used in the flexible pavement in the city of Sabang must be brought from Aceh Besar Regency. This can affect the high operational cost and the insufficient use of local materials. In anticipation of this, the local mountain rocks used are varied with coconut shell ash as a filler and low-density polyethylene (LDPE) plastic use as asphalt substitution. The method used in this study refers to the 2018 specification of Bina Marga (fourth revision of 2010 version). The research results showed that asphalt concrete wearing course (AC-WC), which filler varied with coconut shells (0% and 25% of the weight), meet all predefined parameters. In terms of AC-WC varied with coconut shell and LDPE, the best combination found in this result was 25% of coconut shell ash and 3% of LDPE. AC-WC varied with this best combination has a stability of 1,780.99 kg, the flow of 2.97 mm, VIM of 4.79%, VMA of 16.51%, and VFA of 70.97%.

1. Introduction
The sustainable road infrastructure in the city of Sabang, the most western outer island of Indonesia, should be developed to support tourism, the aspect which according to the Government of Sabang, can accelerate the economy of this city people. However, currently, the materials for asphalt concrete in the city of Sabang are brought from outside the city, which is Aceh Besar Regency. Based on the testing of the mountain reef material located in Ujong Kareung City Sabang, the material’s value of abrasion and the impact meet the specification of Bina Marga Revision 3, 2014, while the specific gravity and the absorption value do not meet the requirements. Because of the low specific gravity, it is indicated that mountain reef material located in Ujong Kareung City Sabang has many large pores, so they will absorb more asphalt and make the asphalt mantle thinner. Mixing this aggregate with 60/70 penetration asphalt results in the stability value of 1,922.13 kg and the durability value of 90.60%, both at the optimum asphalt content of 5.75% [1].

On the other hand, the development of copra coconut business in Sabang has an impact on rising coconut shell waste. If this industry not utilized optimally, it would cause an environmental problem. The content of coconut shell charcoal such as mectosil, lignin, cellulose, and other minerals can increase the value of stability [2]. In addition, the plastic waste can be utilized as an additive in asphalt mixture called. The plastic used as an additive in asphalt mixture is called polymer modified asphalt. Asphalt modification is a mixture of asphalt which is added the substitute material from waste or natural things. One of the polymer materials used to raise the asphalt softening point is the low-density polyethylene.
(LDPE) plastic, which, after substituted to asphalt, improved the dynamic stability by more than 250% and the deformation speed by lower than 24% [3].

Asphalt concrete is a mixture consisting of asphalt as a binder and coarse aggregate, fine aggregate, and filler, as the aggregate materials. The typical procedure of mixing is the hot mixing and compacting method. Based on its type, the concrete asphalt layers are divided into the asphalt concrete wearing course (AC-WC), the asphalt concrete binder course (AC-BC), and the asphalt concrete Base (AC-Base) [4]. The function of hot mixed concrete asphalt is as follows: as a surface coat that is resistant to weather, shear force, and wheel pressure, as a waterproof layer that can protect the layer underneath from water seepage, as the upper foundation layer, and as a layer of foundation in improvement or maintenance activities [5].

The aggregate, which is the main ingredient of the road structure, is a collection of grains of stone and sand or other minerals, both from natural and artificial results. The asphalt concrete contains 90-95% aggregates based on the percent of weight or 75-85% aggregated based on the percent of volume. The aggregate used must be in a clean state of dirt, organic materials, or other materials that are not desirable because they will reduce the performance of the asphalt mixture [4].

The Rock mountain of Weh Island, located in the mountain or hills, has a massive form so that it needs to be separated using human power and the stone-breaking machine. The aggregates from the mountains, hills, and rivers need to go through the process until they have broken fields, rough texture, and the desired size [6].

The filler is a component of asphalt concrete. It is a non-plastic material and must pass the No. 200 filter (0.075 mm), at least 75% of its total weight. Fillers are mixed materials that fill the space between the coarse and fine aggregates, thereby reducing pore volume and increasing density, as well as lowering the permeability value of asphalt mixture [7]. Coconut shell consists of cellulose, mectosil, lignin, and other minerals, while the content of these ingredients varies according to the coconut type. The weight of the coconut shell ranges from 12% of the total weight of the whole coconut. The effect of the hardness of the shell structure is the richness of the content of silica (SiO2) [8]. The chemical composition of the coconut shell is shown in table 1.

| Test Result       | Unit | Testing parameters |
|-------------------|------|--------------------|
| Carbon            | %    | 91.38              |
| Ash content       | %    | 4.79               |
| Water content     | %    | 3.83               |
| Weight type       | gr/cm³ | 0.5722           |

The asphalt is a material of black or dark brown and has an adhesive substance with the main element of bitumen obtained from the natural or residue from the refining of petroleum. The example of the natural asphalt is the asphalt of Buton Island (asbuton) and the asphalt that exists in the Lake of Trinidad (Trinidad Lake asphalt). Residue asphalt, called oil asphalt, is the result of petroleum distillation [10]. The addition of low-quality plastic of LDPE can increase the asphalt softening point and reduce asphalt penetration. The resilient modulus of the asphalt mixture added with LDPE is better than the conventional asphalt in terms of density, stability, MQ, VFB [3].

The aggregate gradation is used to set the pore volume in the mixed aggregate. The aggregate gradation is produced by screening analysis, which can be done in dry or wet conditions. The aggregate gradation is expressed against the percentage of escaped aggregate to the total aggregate weight [10]. The aggregate gradation for the AC-WC mixture corresponds to the specifications shown in table 2.
Table 2. Aggregate gradation specifications for the asphalt concrete wearing course (AC-WC) [11].

| Size of sieve ASTM | % Passing weight AC-WC |
|--------------------|------------------------|
| 3/4”               | 100                    |
| 1/2”               | 90 – 100               |
| 3/8”               | 77 – 90                |
| No. 4              | 53 – 69                |
| No. 8              | 33 – 53                |
| No. 16             | 21 – 40                |
| No. 30             | 14 – 30                |
| No. 50             | 9 – 22                 |
| No. 100            | 6 – 15                 |
| No. 200            | 4 – 9                  |

Figure 1. Aggregate gradation chart for test objects.

2. Methodology
The research methods used are the standard of Bina Marga, American Association of State Highway and Transportation Officials, and from other acknowledged institutions. This research will be conducted in the Road Laboratory of The Faculty of Engineering, Syiah Kuala University, Banda Aceh. The testing stages are as follows:
1. The testing of the physical properties of the aggregate, which are the test of impact, abrasion, flakiness index, elongated index, specific gravity, and absorption.
2. The testing of the physical properties of the asphalt, which are specific gravity, softening point, penetration, and ductility.
3. Calculation of the initial estimation of the middle asphalt rate (Pb) using equation (1) below.

\[ Pb = 0.035(\%CA) + 0.045(\%FA) + 0.18(\%Filler) + K \]  (1)
Description:
P_b = Middle/ideal asphalt rate;
CA = The aggregate held in No. 4 filter;
FA = The aggregate passing No. 4 sieve and held No. 200 sieve;
Filler = The aggregate, 75% of which passes No. 200 filter;
K = Constants for asphalt concrete, which is 0.5–1.

The Pb value obtained in this study is 6%. Five types of AC-WC asphalt content (5%, 5.5%, 6%, 6.5%, 7%) were determined based on the Pb value which is added with 0%, 0.5%, 1%, -0.5%, -1%, as stated in the standard. Three test objects represented every asphalt content.

a. Test objects to determine the optimum asphalt content;
b. Test objects combined with coconut ash shell filler and portland cement, both for filler;
c. Test objects combined with the coconut ash and Portland cement, in the best combination, and LDPE substituted in Pen. 60/70 asphalt, using dry mixing method;
d. Test objects for durability tests.

There are 15 pieces of asphalt objects used to determine the optimum asphalt content. The number of test objects can be seen in table 3.

### Table 3. Test items to determine optimum asphalt content.

| Asphalt Content | Test Item code | Amount |
|-----------------|----------------|--------|
| 5.0%            | A11, A12, A13  | 3 pieces |
| 5.5%            | A21, A22, A23  | 3 pieces |
| 6.0%            | A31, A32, A33  | 3 pieces |
| 6.5%            | A41, A42, A43  | 3 pieces |
| 7.0%            | A51, A52, A53  | 3 pieces |

Amount of test objects = 15 pieces

The optimum asphalt content was determined using the overlapping method. After that, 45 pieces of test objects were tested, as described in table 4.

### Table 4. Test items with coconut shell ash filler and portland cement.

| Filler combination | Asphalt content | Test item code | Amount |
|--------------------|-----------------|----------------|--------|
| 0% CSA: 100% PC    | KAO(Bw)         | B11, B12, B13  | 9 pieces |
|                    | KAO             | B21, B22, B23  |        |
|                    | KAO(At)         | B31, B32, B33  |        |
| 25% CSA: 75% PC    | KAO             | C11, C12, C13  | 9 pieces |
|                    | KAO(Bw)         | C21, C22, C23  |        |
|                    | KAO(At)         | C31, C32, C33  |        |
| 50% CSA: 50% PC    | KAO             | D11, D12, D13  | 9 pieces |
|                    | KAO(At)         | D21, D22, D23  |        |
|                    | KAO(Bw)         | D31, D32, D33  |        |
| 75% CSA: 25% PC    | KAO             | E11, E12, E13  | 9 pieces |
|                    | KAO(At)         | E21, E22, E23  |        |
|                    | KAO(Bw)         | E31, E32, E33  |        |
| 100% CSA: 0% PC    | KAO             | F11, F12, F13  | 9 pieces |
|                    | KAO(Bw)         | F21, F22, F23  |        |
After obtaining the best CSA-PC filler combinations, the test items were made with asphalt, 5.92% (optimum content) of AC-WC weight, containing LDPE, and with the best CSA-PC filler combinations. The description of the test objects is in Table 5.

**Table 5. Test items with LDPE waste substitutions.**

| LDPE Content | Asphalt Content | Test Item code | Amount |
|--------------|----------------|----------------|--------|
| 1%           | KAO            | G₁₁, G₁₂, G₁₃ | 3 pieces |
| 2%           | KAO            | G₂₁, G₂₂, G₂₃ | 3 pieces |
| 3%           | KAO            | G₃₁, G₃₂, G₃₃ | 3 pieces |
| 4%           | KAO            | G₄₁, G₄₂, G₄₃ | 3 pieces |
| 5%           | KAO            | G₅₁, G₅₂, G₅₃ | 3 pieces |

| Amount | 15 pieces |

LDPE: low-density polyethylene

Note: CSA: coconut shell additive

PC: portland cement

KAO: optimum asphalt content

After obtaining the best combination of AC-WC with LDPE and CSA-PC, the test objects with the best combination of LDPE and CSA-PC were tested for durability, at a 30 minute and 24-hour immersion. All durability tests, including the durability tests for the former test objects, were shown in Table 6.

**Table 6. The number of test objects for durability testing with 30 minute and 24-hour immersion.**

| Test items types                                              | 30 minutes | 24 hours | Amount |
|--------------------------------------------------------------|------------|----------|--------|
| Test objects for optimum asphalt content determination        | 3          | 3        | 6 pieces |
| Test objects with the combination of CSA and PC as filler     | 3          | 3        | 6 pieces |
| Test objects added with LDPE with dry method                 | 3          | 3        | 6 pieces |

| Amount | 18 pieces |

3. Results and discussion

3.1. Results of the examination of physical properties

The result of the inspection of the physical properties of mountain rock aggregate located in Ujong Kareung Sukakarya subdistrict, Sabang City, is presented in Table 7. The results of the inspection of the physical properties of Pen. 60/70 asphalt is presented in Table 8.

**Table 7. Results of inspection of the physical properties of mountain rock aggregate.**

| Properties          | Unit | Results | Specifications of Bina Marga (2018) |
|---------------------|------|---------|------------------------------------|
| Specific gravity    | -    | 2.42    | Min. 2.5                           |
| Absorption          | %    | 2.71    | Maks. 3                            |
| Weight of contents  | kg/dm³ | 1.20   | Min. 1                             |
Flakiness index % 15.00 Maks. 10
Elongated index % 14.18 Maks. 10
Impact % 13.51 Maks. 30
Abrasion % 25.93 Maks. 40

**Table 8.** The results of the inspection of the physical properties of pen. 60/70 asphalt.

| Properties          | Unit  | Results | Specifications of Bina Marga (2018) |
|---------------------|-------|---------|------------------------------------|
| Specific gravity    |       | 1.03    | Min. 1                             |
| Penetration         | 0.1 mm| 65      | 60 – 70                            |
| Softening point     | º C   | 48.5    | Min. 48                            |
| Ductility, 25º C    | cm    | 120     | Min. 100                           |

3.2. Marshall test results

Based on Marshall test results, which are stability, flow, VIM, VMA, and VFA, the optimum asphalt content of AC-WC composed of only aggregate, filler of portland cement, and asphalt, is 5.92%. Recapitulation of Marshall test results for determination of optimum asphalt content of the AC-WC mixture is presented in table 9.

**Table 9.** Recapitulation of Marshall test results to determine optimum asphalt content.

| Mixed characteristics | Asphalt Content ( % ) | Specifications of Bina Marga (2018) |
|-----------------------|-----------------------|------------------------------------|
|                       | 5.00  | 5.50  | 6.00  | 6.50  | 7.00  |                  |
| Stability (Kg)        | 1,908.21 | 1,888.93 | 1,850.38 | 1,869.66 | 1,792.56 | Min. 800        |
| Flow (mm)             | 3.07  | 3.30  | 3.63  | 3.80  | 4.33  | 2 – 4           |
| VIM (%)               | 5.36  | 4.70  | 3.77  | 3.17  | 2.20  | 3 – 5           |
| VMA (%)               | 15.97 | 16.37 | 16.55 | 17.01 | 17.15 | Min. 15         |
| VFA (%)               | 66.43 | 71.36 | 77.21 | 81.35 | 87.18 | Min. 65         |

The Marshall characteristics obtained from the Marshall test were plotted on the several cross axis with coordinates of the asphalt content as the x-axis and the Marshall parameter as the y-axis, to facilitate the calculation of the regression analysis. Optimum asphalt content obtained is 5.92%.

In table 10-12, it indicates that the higher percentage of CSA, the lower the stability value. The stability value for all combinations of CSA filler variations still meets the requirements of min. 800 kg. Flow value inversely proportional to stability. The value of flow is influenced by the comparison of the asphalt mixture. In the table above, it shows that the flow value increases when the CSA level increases. This phenomenon occurs because of the influence of CSA substitution in asphalt which causes the asphalt to become mushier. The decrease in the value of VIM is caused by the increased percentage of the CSA. The VMA value tends to decrease as CSA fillers increase in asphalt mixtures. The VFA value is getting larger with the increased variance rate of CSA fillers in asphalt mixtures; this can occur due to the increased volume of CSA.
Table 10. Recapitulation of the Marshall test result of ACWC, containing 5.42% asphalt, substituted with coconut shell ash filler.

| Mixed characteristics | Variety of filler CSA-PC | Specifications of Bina Marga (2018) |
|-----------------------|--------------------------|----------------------------------|
|                       | 0%  | 25%  | 50%  | 75%  | 100% |                     |
| Stability (kg)        | 1,676.91 | 1,638.36 | 1,607.52 | 1,665.35 | 1,229.73 | Min. 800          |
| Flow (mm)             | 2.27   | 2.70   | 3.07   | 3.30   | 3.53   | 2 - 4             |
| VIM (%)               | 4.74   | 4.73   | 2.43   | 2.04   | 1.53   | 3 - 5             |
| VMA (%)               | 16.25  | 15.60  | 12.97  | 12.08  | 11.14  | Min. 15           |
| VFA (%)               | 70.84  | 69.68  | 81.25  | 83.26  | 86.25  | Min. 65           |

Note: CSA: coconut shell ash  
PC: portland cement

Table 11. Recapitulation of the marshall test result of AC-WC, containing 5.92% asphalt, substituted with coconut shell ash filler.

| Mixed characteristics | Variety of filler CSA-PC | Specifications of Bina Marga (2018) |
|-----------------------|--------------------------|----------------------------------|
|                       | 0%  | 25%  | 50%  | 75%  | 100% |                     |
| Stability (kg)        | 1,780.99 | 1,727.03 | 1,634.51 | 1,649.93 | 1,345.38 | Min. 800          |
| Flow (mm)             | 2.50   | 2.77   | 2.50   | 3.13   | 4.07   | 2 - 4             |
| VIM (%)               | 4.23   | 4.06   | 2.06   | 1.51   | 1.23   | 3 - 5             |
| VMA (%)               | 16.78  | 15.94  | 13.55  | 12.49  | 11.71  | Min. 15           |
| VFA (%)               | 74.87  | 74.61  | 84.81  | 87.95  | 89.55  | Min. 65           |

Table 12. Recapitulation of the marshall test result of AC-WC, containing 6.42% asphalt, substituted with coconut shell ash filler.

| Mixed characteristics | Variety of filler CSA-PC | Specifications of Bina Marga (2018) |
|-----------------------|--------------------------|----------------------------------|
|                       | 0%  | 25%  | 50%  | 75%  | 100% |                     |
| Stability (kg)        | 1,811.83 | 1,750.15 | 1,684.62 | 1,727.03 | 1,445.61 | Min. 800          |
| Flow (mm)             | 2.63   | 2.68   | 2.73   | 3.37   | 3.47   | 2 - 4             |
| VIM (%)               | 3.62   | 3.33   | 1.66   | 1.19   | 1.15   | 3 - 5             |
| VMA (%)               | 17.24  | 16.24  | 14.11  | 13.07  | 12.48  | Min. 15           |
| VFA (%)               | 79.04  | 79.48  | 88.29  | 90.92  | 90.81  | Min. 65           |

Table 13 shows the value of stability increases because of the increase in the percentage of LDPE, which can provide a strong bonding between particles in the asphalt mixture. Contrarily, the flow value of the AC-WC increases as the percentage of LDPE plastic decreases. The table also shows the increase in the value of VIM caused by the increase in the amount of LDPE into the asphalt mixture, but this is only at the variation of 1% - 3%. It can be seen also that the percentage of LDPE in the asphalt mixture can increase VMA value and decrease VFA value.
Table 13. Recapitulation of the Marshall test result of AC-WC substituted with LDPE.

| Mixed characteristics | Variations of LDPE substitutions | Specifications of Bina Marga (2018) |
|-----------------------|----------------------------------|-----------------------------------|
| Stability (kg)        | 1% 1,730.88, 1,765.57, 1,780.99, 1,773.28, 1,804.12 | Min. 1000 |
| Flow (mm)             | 2% 3.48, 3.23, 2.97, 3.00, 2.57 | 2 - 4 |
| VIM (%)               | 3% 4.12, 4.42, 4.79, 5.22, 5.57 | 3 - 5 |
| VMA (%)               | 4% 15.94, 16.20, 16.51, 16.87, 17.17 | Min. 15 |
| VFA (%)               | 5% 74.23, 72.76, 70.97, 69.09, 67.59 | Min. 65 |

Table 14. Result of durability testing.

| Types of asphalt mixture | Soaking stability, 30 minutes | Soaking stability, 24 hours | Durability (%) |
|-------------------------|--------------------------------|----------------------------|----------------|
| Test object with optimum asphalt content (5.92%) | 1,719.32 | 1,567.43 | 91.17 |
| Test object containing coconut shell ash (CSA) filler substitution with optimum asphalt content (5.92%) | 1,754.01 | 1,480.31 | 84.40 |
| Test object containing LDPE substitution with dry mixing method and with optimum asphalt content (5.92%) | 1,769.43 | 1,530.42 | 86.49 |

Figure 2. The durability of asphalt mixture.

The durability value of the asphalt mixture (see figure 2) with standard material meets the requirements, while the durability value of the asphalt mixture substituted with coconut shell ash and LDPE does not meet the requirements. The low durability of the asphalt mixture is caused by the coconut shell ash which properties as organic material are susceptible to water influence.
4. Conclusion
The Sabang Mount rock, used as the material of AC-WC substituted with coconut shell ash filler and LDPE penetration-60/70-asphalt substitution in dry method, meets the requirement of 2010 Bina Marga (fourth revision, 2018). Based on the Marshall test results, the best combination of the substitution in the AC-WC is 25% of CSA and 75% of PC for filler, 3% LDPE of asphalt content, and 5.92% of asphalt content; AC-WC in this combination satisfies all Marshall parameters. AC-WC with standard material obtains the best durability value, which meets the required value of 91.17%, while the durability value of AC-WC substituted with CSA and LDPE is less than 90%.

The results of this research can be used as a reference in the optimization of the usage of the Sabang Mountain rock as the primary material in the asphalt concrete. The recommended further research is a combination of coconut shell ash (CSA) filler and LDPE substitution on asphalt pen. 60/70 in AC-WC using a wet mixing method.

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