Analysis of the usage of rubberized asphalt in hot mix asphalt using Reclaimed Asphalt Pavement (RAP)

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Abstract. There has been an increasing demand in using more environmentally friendly materials in pavement construction. One of the alternative materials that have been widely used is the Reclaimed Asphalt Pavement (RAP) aggregates. The RAP aggregates are derived from the crushed and screened pavement materials that contain asphalt and aggregates. This material is usually combined with natural aggregates and virgin asphalt binder to construct a new pavement. There have been numerous positive feedbacks in using this material although RAP aggregates also have certain weaknesses, such as questionable interaction between virgin and recycled materials and increased stiffness of RAP binder. Moreover, there has been a push on using rubber as an additive to asphalt binder to improve the welfare of rubber farmers. This research combines the usage of both latex and RAP as the ingredients to design hot mix asphalt (HMA) as latex could help in improving the flexibility of HMA and the interaction between the virgin and recycled materials. The main objective of this research is to find a suitable percentage of RAP aggregates to be used in HMA with certain percentage of latex as the binder additive.

Keywords: hot mix asphalt, Reclaimed Asphalt Pavement, aggregates, pavement.

1. Introduction

Indonesia has been conducting a massive development on infrastructure in many areas of Indonesia, including expanding the road and highway network. The processes involved in road construction are generally not environmentally friendly as the production of asphalt generates air pollution and the aggregates used are sourced from quarries, which usually use explosive tools to obtain aggregates from a hill or a mountain. This quarrying process damages the environment, while the aggregates are highly needed in the road construction process.

There are a number of research studies that have been studying alternative materials to be used as aggregates and/or to recycle or reuse the aggregates. One of the alternative materials is the Reclaimed Asphalt Pavement (RAP) aggregates. These aggregates are derived from the asphalt pavements that have been removed from road reconstruction or resurfacing process. These materials could be crushed and screened to be used as high-quality, well graded aggregates [1]. The RAP aggregates have been widely used in road construction project and have been praised for their advantages in reducing...
material cost and waste and having a good performance when mixed with natural aggregates [2]. However, RAP aggregates have some weaknesses, such as the questionable interaction between virgin and recycled materials[2] and increased stiffness of RAP binder [3].

Currently, In Indonesia, there has been a push to use rubberized asphalt in road construction to increase the welfare of rubber farmers [4]. The use of rubber or latex as an additive in asphalt has been used in Indonesia according to the guideline issued by Bina Marga [5]. Due to its nature, latex would be able to fix the stiffness problem faced with RAP materials and to help in improving the interaction between the virgin binder and the recycled materials. Therefore, this research attempts to combine the usage of both rubber or latex and RAP as the ingredients to design hot mix asphalt (HMA). The main objective of this research is to find a suitable percentage of RAP aggregates to be used in HMA with certain percentage of latex as the binder additive.

2. Experimental design

2.1. Material
In this research, there are two different aggregates used, namely the natural and the RAP aggregates, as shown in Figure 1 and Figure 2. With these two aggregates, there were five aggregate combinations studied in this research, as listed in Table 1. These combinations were mixed using asphalt and rubberized asphalt binders. Two samples were constructed for each percentage of asphalt content (5%, 7.5%, and 10%). The RAP aggregates used herein contain 5.71% of binder based on the extraction test conducted.

Table 1. Aggregates composition for each combination

| Combination | 1 | 2 | 3 | 4 | 5 |
|-------------|---|---|---|---|---|
| Natural aggregate | 100% | 75% | 70% | 65% | - |
| RAP aggregate | - | 25% | 30% | 35% | 100% |

The aggregates were crushed into four sizes, as shown in Table 2. The coarsest aggregates are Aggregate I and the finest aggregates are Aggregate IV. The asphalt samples were then constructed by using the asphalt mix design used in [6], as shown in Table 3.

Table 2. Aggregates grading

| Aggregate | Passed Sieve No. | Retained by Sieve No. |
|-----------|-----------------|-----------------------|
| I         | ¾" (19.1 mm)    | 3/8" (9.6 mm)         |
| II        | 3/8" (9.6 mm)   | #8 (2.4 mm)           |
| III       | #8 (2.4 mm)     | #16 (1.2 mm)          |
| IV        | #16 (1.2 mm)    | #200 (0.075 mm)       |

Table 3. Composition of asphalt mix design

| Asphalt Content | Weight of Aggregate (gr) |
|-----------------|--------------------------|
| %              | I | II | III | IV |
| 4.5             | 52.87 | 242 | 193 | 181 | 476 |
| 5.5             | 66 | 242 | 193 | 181 | 476 |
| 6.0             | 71.62 | 242 | 193 | 181 | 476 |
2.2. Laboratory tests
To ensure the suitability of the materials to be used in HMA design, there are several standard tests for coarse and fine aggregates and asphalt, as listed in Table 4, conducted. Due to the limited amount of RAP aggregates, the tests were only conducted for the natural aggregates.

| Test                          | Standard                              |
|-------------------------------|---------------------------------------|
| Aggregate Tests               |                                       |
| Bulk Specific Gravity         | SNI 1969:2008 (Coarse) and SNI 1970:2008 (Fine) |
| SSD Specific Gravity          | SNI 1969:2008 (Coarse) and SNI 1970:2008 (Fine) |
| Apparent Specific Gravity     | SNI 1969:2008 (Coarse) and SNI 1970:2008 (Fine) |
| Absorption                    | SNI 1969:2008 (Coarse) and SNI 1970:2008 (Fine) |
| Los Angeles Abrasion          | SNI 2417:2008                         |
| Asphalt Tests                 |                                       |
| Penetration Test at 25°C      | SNI 06-2456-1991                     |
| Softening Point Test          | SNI 2434-2011                        |
| Specific Gravity              | SNI 2441-2011                        |
| Ductility at 25°C             | SNI 2432-2011                        |
| Flash and Fire Point Test     | SNI 06-2433-1991                     |

Additionally, the Marshall Stability and Flow Test was conducted for the prepared asphalt samples according to *Standar Nasional Indonesia* (SNI) 06-2489-199 to determine the characteristics of the asphalt mixes. From the Marshall test, there were some parameters calculated, such as stability, flow, Void in Mix (VIM), Void in Mineral Aggregate (VMA), Void Filled with Asphalt (VFA), and density.

3. Results and Discussion

3.1. Materials Description
Table 5 shows the results of the tests conducted on the coarse and fine aggregates. It was found that the natural aggregates passed most of the requirements, except for the specific gravity and absorption parameters, which indicates that the aggregates are not dense enough. However, this is the type of aggregates that is commonly used for road construction, and hence, it will be used in this research.

| Tests                              | Coarse Aggregates | Fine Aggregates | Requirement      |
|------------------------------------|-------------------|-----------------|------------------|
| Bulk Specific Gravity              | Aggregate I       | Aggregate II    | Aggregate III    | Aggregate IV    | ≥ 2.5 gr/cc |
| SSD Specific Gravity               | 2.303             | 2.396           | 2.420            | 2.370           |
| Apparent Specific Gravity          | 2.370             | 2.505           | 2.700            | 2.883           |
| Absorption (%)                     | 2.666             | 2.689           | 2.675            | 2.733           |
| Loss of Material (%)               | 2.86              | 4.54            | 3.82             | 5.48            | ≤ 3         |

Table 6 shows the results of the tests conducted on both asphalt and rubberized asphalt. It can be seen that both binders passed all the requirements. However, it is important to note that there are two
requirements that are different for both binders, namely the penetration value and softening point. The rubberized asphalt binder requires a lower penetration value and a higher softening point value. This was done because due to oxidation that could occur during the mixing process will accelerate the loss of bonding between the asphalt and the aggregates [7].

Table 6. Asphalt test results

| Tests                      | Unit | Asphalt Value | Requirement | Rubberized Asphalt Value | Requirement |
|----------------------------|------|---------------|-------------|--------------------------|-------------|
| Penetration Test at 25°C   | 0,1 mm | 62            | 60-70       | 50                        | 40-60       |
| Specific Gravity           | gr/cc | 1.07          | ≥ 1.0       | 1.05                      | ≥ 1.0       |
| Ductility at 25°C          | cm   | 105           | ≥ 100       | 108                       | ≥ 100       |
| Softening Point Test       | °C   | 62            | ≥ 48        | 55                        | ≥ 54        |
| Flash Point Test           | °C   | 365.5         | ≥ 232       | 327.5                     | ≥ 232       |
| Fire Point Test            | °C   | 384           | ≥ 288       | 349                       | ≥ 288       |

3.2. Characteristics of Asphalt Mixture

Figure 3 shows the characteristics for each combinations of asphalt mixture. The characteristics measured include stability, flow, VIM, VFA, VMA, and density. The x-axis shows the percentage of asphalt in the mixture and the y-axis shows the value of each parameter measured. The red lines placed on the graphs indicate the minimum value or the desired range of value.

From the data obtained, the optimum asphalt content for each combination can be determined, and the values are listed in Table 7. The maximum optimum asphalt content is 9%, which suggests that the data obtained for 10% asphalt content can be disregarded because too much of asphalt in the mixture will definitely lead to poor performance of the asphalt mix. Therefore, in the following discussion, results for 10% asphalt content were not going to be discussed.

Table 7. Optimum Asphalt Content for each combination

| Combination | Optimum Asphalt Content (%) |
|-------------|-----------------------------|
| 1           | 9                           |
| 2           | 5.8                         |
| 3           | 5.8                         |
| 4           | 5.4                         |
| 5           | 7.1                         |

The results for Combination 1, which used 100% natural aggregates, performed relatively well, although the stability of this combination is the lowest amongst all combinations. However, the amount of binder needed for this combination is above the others (as seen in Table 7).

Looking at the results displayed in Figure 3, the results for Combination 5, which used 100% RAP as the aggregates, are very different to the other combinations. Combination 5 has the highest stability value for 5% and 7.5% asphalt content, which indicate that HMA designed using 100% RAP has the potential to be used. However, looking at the VFA, VIM, VMA, and density results that did not meet the standard, there is an issue during the compaction process for Combination 5. This could be caused because the RAP aggregates were manually crushed and did not use the mechanical crusher, and thus, although the aggregates passed the required sieves, but the shape might not be ideal.

Comparing the test results for Combination 2, Combination 3, and Combination 4, it can be seen that there is an increase in the stability of the asphalt samples as the percentage of RAP in the asphalt
samples increases. The performances of these combinations are better than Combination 5 as the VFA, VIM, VMA, and density results met the required standard.

By looking at the performance of all combinations, Combination 4 is the most recommended one to be used.

Figure 3. The laboratory test results for asphalt mixes

3.3. Characteristics of Rubberized Asphalt Mixture

Figure 4 shows the characteristics for each combinations of rubberized asphalt mixture. The characteristics measured include stability, flow, VIM, VFA, VMA, and density. The x-axis shows the percentage of asphalt in the mixture and the y-axis shows the value of each parameter measured. The red lines placed on the graphs indicate the minimum value or the desired range of value.

From the data obtained, the optimum asphalt content for each combination can be determined, and the values are listed in Table 8. The maximum optimum asphalt content is 7.3 %, which suggests that the data obtained for 10% asphalt content can be disregarded because too much of asphalt in the mixture will definitely lead to poor performance of the asphalt mix. Therefore, similar to previous discussion, in the following discussion, results for 10% asphalt content were not going to be discussed.
### Table 8. Optimum Asphalt Content for each combination

| Combination | Optimum Asphalt Content (%) |
|-------------|----------------------------|
| 1           | 7.3                        |
| 2           | 6.8                        |
| 3           | 6.5                        |
| 4           | 6.0                        |
| 5           | 5.9                        |

The results for Combination 1, which used 100% natural aggregates, performed relatively well, although the stability of this combination is the lowest amongst all combinations. However, the amount of binder needed for this combination is above the others (as seen in Table 7), which is caused by the high percentage of air voids in the mixture. The VFA and VMA results exceeded the standard, which might cause issue in the mixture.

Looking at the results displayed in Figure 4, the results for Combination 5, which used 100% RAP as the aggregates, are very different to the other combinations. Combination 5 has the highest stability value for 5% and 7.5% asphalt content, which indicate that HMA designed using 100% RAP has the potential to be used. However, looking at the VFA, VIM, VMA, and density results that did not meet the standard, there is an issue during the compaction process for Combination 5. This could be caused because the RAP aggregates were manually crushed and did not use the mechanical crusher, and thus, although the aggregates passed the required sieves, but the shape might not be ideal.

Comparing the test results for Combination 2, Combination 3, and Combination 4, it can be seen that there is not much difference in the stability of the asphalt samples as the percentage of RAP in the asphalt samples increases. Looking at the VIM And VFA parameters, Combination 4 performs better than Combination 2 and Combination 3.
4. Summary and Conclusions
In this research, there are five HMA designs tested by using RAP aggregates and both asphalt and rubberized asphalt binders were used and compared. From the research findings, it can be concluded that:

- The stability of the mix increases as the percentage of RAP increases for 5% and 7.5% of asphalt binder;
- The stability of Combination 5 is the highest when mixed with 5% asphalt binder;
- The usage of rubberized asphalt can decrease the amount of binder needed; and
- 35% RAP aggregates are seen to be an ideal percentage to be added to the HMA mixture using both asphalt and rubberized asphalt binders.

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