The usage of recycled materials on hot mix asphalt

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Abstract. The demand for fresh aggregates increases as the number of road maintenance and construction project increases. However, continually mining fresh aggregates will result in irrecoverable environmental damage, and thus, engineers are looking for alternatives aggregates that are more environmentally friendly to be used. The paper discussed the usage of several recycled materials that were mixed with hot mix asphalt (HMA) to be used as surfacing pavement layer, including coconut fibre, Styrofoam, crumb rubber, and recycled asphalt pavement (RAP). A number of tests, which are Marshall, Cantabro Loss, and Indirect Tensile Strength tests were used to evaluate the performance of the asphalt mixtures that were mixed with recycled materials. Both coconut fibre and RAP were mixed as filler or substitute for fresh aggregates, while both Styrofoam and crumb rubber were melted and mixed with the binder. It is found that best amount for coconut fibre, RAP, Styrofoam, and crumb rubber to be added to the HMA are 0.6\% of total binder weight, 100\% of coarse aggregates, 2.5\% of the binder weight, and 3\% of total mixture weight, respectively.

Keywords: mix asphalt (HMA), recycled asphalt pavement (RAP), recycled materials

1. Introduction

The utilization of recycled materials in road maintenance projects should be considered as it can conserve resources, preserve the environment, and maintain the existing road geometrics [1]. There are a number of materials that can be used as substitute for fresh aggregates, such as glass, plastic, tyre rubber, fly ash, and slag [2]. The crumb rubber and Styrofoam were chosen as they are one of the waste that are widely available and are available in a large amount [3]. Crumb rubber, however, has been studied to improve the HMA properties, such as increase the amount of recoverable deformation and reduce the resilient modulus value, which resulted in a more elastic and more resilient pavement [4]. Similarly, the usage of Styrofoam and coconut fibre as one of the materials in HMA has been able to improve the stability of HMA [5], [6].

RAP materials are aggregates that were derived from asphalt surfacing layers that have been removed from pavement layers for reconstruction or resurfacing purposes. These materials can be crushed and sieved to be well graded aggregates [7]. RAP aggregates have been applied in many projects as they can reduce the material cost and perform well when mixed with fresh natural aggregates [8]. The purpose of this study is to evaluate and compare the performance of four wastes materials to be used in hot mix asphalt (HMA), such as crumb rubber, Styrofoam, coconut fibre, and reclaimed asphalt pavement (RAP).
2. Experimental design

2.1. Materials
HMA consists of aggregates, binder (asphalt), and filler (optional). In this research, the aggregates grading used followed the research done by [9]. The binder used was 60/70 penetration asphalt and natural aggregates were used in the mixture. Both aggregates and binder have been tested for their suitability according to Standar Nasional Indonesia (SNI). The recycled materials were added at different percentages and by different methodologies as summarized in Table 1.

| Table 1. Recycled Materials Weight and Mixing Methods |
|-----------------|-----------------|-----------------|
| Materials       | Weight (%)      | Mixing Methods  |
| Coconut fibre   | 0.2, 0.4, and 0.6 of the total aggregates weight | As filler       |
| RAP             | 50%, 75%, and 100% of the total coarse aggregate weight | As coarse aggregate substitute |
| Crumb rubber    | 1%, 2%, and 3% of the total mixture weight | Melted and mixed with binder |
| Styrofoam       | 1.5%, 2%, and 2.5% of the total binder weight | Melted and mixed with binder |

2.2. Laboratory tests
There were three tests that were conducted to assess the performance of the prepared specimens, which are the Marshall, Cantabro Loss, and Indirect Tensile Strength (ITS) tests. The Marshall tests were conducted according to SNI 06-2489-199 [10] to determine the characteristics of the prepared specimens. The parameters that can be determined from this test are stability, flow, Void in Mix (VIM), Void in Mineral Aggregate (VMA), Void Filled with Asphalt (VFA), and density.

Both Cantabro Loss and ITS tests were conducted to assess the performance of the specimens when subjected to water. The detailed procedure and the limitations faced when conducting the experiments can be found in [11].

3. Results and discussion
3.1. Test results
Table 2 shows the results of the tests conducted on both coarse and fine aggregates, while Table 3 shows the results of the tests conducted on the asphalt binder. It can be seen that both binder and aggregates passed all the requirements. Table 3 also includes the test results for the asphalt binders that were mixed with Styrofoam and crumb rubber. The modified binders met all the requirements except for the penetration test result for the asphalt mixed with crumb rubber, which was slightly higher than the limit for the asphalt to be included in 60/70 penetration category.

| Table 2. Aggregate Test Results |
|-----------------|-----------------|-----------------|-----------------|
| Tests           | Coarse Aggregates | Fine Aggregates | Requirement     |
| Bulk Specific Gravity | 2.51            | 2.55            | ≥ 2.5 gr/cc     |
| SSD Specific Gravity | 2.56            | 2.74            |                |
| Apparent Specific Gravity | 2.64            | 2.69            |                |
| Absorption (%)  | 1.99            | 1.97            | ≤ 3             |
Table 3. Asphalt Test Results

| Tests                        | Unit     | Asphalt | Asphalt & Crumb Rubber | Asphalt & Styrofoam | Requirement |
|------------------------------|----------|---------|-------------------------|---------------------|-------------|
| Penetration Test at 25°C     | 0.1 mm   | 69      | 72                      | 65                  | 60-70       |
| Specific Gravity             | gr/cc    | 1.43    | 1.33                    | 1.26                | ≥ 1.0       |
| Ductility at 25°C            | cm       | 102.5   | 107.5                   | 100                 | ≥ 100       |
| Softening Point Test         | ºC       | 49      | 41                      | 47                  | ≥ 48        |
| Flash Point Test             | ºC       | 220     | 212                     | 240                 | ≥ 232       |

3.2. Marshall test results

Figure 1 shows the parameters generated from Marshall tests, which are stability, flow, VIM, VFA, VMA, and density. The stability values of all sample variations exceed the required amount, which is 800 kg. For the samples mixed with crumb rubber, RAP, and Styrofoam, it can be seen that the more recycled materials added into the mixture, the higher the stability values will be. For the samples mixed with coconut fibre, there is no clear effect on increasing the amount of coconut fibre into the mixture. All sample variations have higher stability values than the control sample, which suggests that adding recycled materials can improve the stability of the asphaltic mixture, except when added with 0.4% of coconut fibre.

The flow values need to be between 2 and 4 millimetres (mm). The samples mixed with crumb rubber and coconut fibre generally met the requirement. However, none of the samples mixed with Styrofoam met the requirement. For the VIM values, only the samples mixed with 50% RAP satisfy the standard, which is between 3% and 5%, while all sample variations have VFA higher than 65%, which is what is being required. For the VMA values, none of the samples reached the minimum value of 15%. This data suggests that the samples were very dense and the voids between aggregates were filled with the asphalt, and this could explain why the stability values were high. Adding recycling material into the asphaltic mixture generally decreases the VIM and increases the density of the samples.

Based on the Marshall test results, it is recommended that the crumb rubber, RAP, coconut fibre, and Styrofoam, to be used at 3%, 100%, 0.6%, and 2.5%, respectively. However, it is important to note that the strength or the stability of the prepared asphaltic mixture samples was obtained most likely from the density of the asphaltic mixture. This could potentially cause some workability issue when applying the mixture in field. Also, if the amount of void in mixture is too low, some potential problems that could occur include bleeding and over compaction on the asphalt mixture. This could be overcome by modifying the aggregate grading to have more of coarse aggregate, and hence, more void can be obtained.
Figure 1. Marshall Test Results for All Sample Variations: a) stability, b) flow, c) VIM, d) VFA, e) VMA, and f) density
3.3. Cantabro Loss test results

Figure 2 shows the results of Cantabro Loss tests, which are represented by Cantabro Abrasion Loss (CAL) in percentage. The higher the percentage of CAL suggests that the specimens are more susceptible to water. For the samples mixed with crumb rubber and RAP, it can be seen that the higher the percentage of crumb rubber and RAP, the higher the CAL values are, which means the addition of recycled materials made the samples more susceptible to water. For the samples mixed with coconut fibre and Styrofoam, increase in recycled materials percentage, results in no clear pattern can be observed in regards to CAL values.

Comparing all data, it can be seen that the samples mixed with coconut fibre had the lowest CAL values compared to the other sample variations and the control sample. It means that the presence of coconut fibre in the asphalt mixture was able to strengthen the interaction between the binder and the aggregates, even with the presence of moisture.

Based on the Cantabro Loss test results, it is recommended that the crumb rubber, RAP, coconut fibre, and Styrofoam, to be used at 3%, 100%, 0.6%, and 2.5%, respectively.

![Figure 2. Cantabro Loss test results for all sample variations](image)

3.4. ITS test results

Figure 3 shows the comparison between the average ITS test results at dry and wet conditions. It can be seen that the stability values of the prepared samples at dry condition were higher than the prepared samples at wet condition. This observation is as expected since the immersed samples would have been exposed to moisture, and hence, would be weaker. It can be seen that for samples mixed with crumb rubber, the higher the percentage of crumb rubber added, the lower the stability values of the samples at both dry and saturated conditions. These samples had stability values lower than the control sample. This is different to the finding that was observed with the Marshall test, but ITS and Marshall tests were conducted using different devices that had different setup and procedure. The ITS test is also used to predict fracture strength, while the Marshall test is unable to be used for that purpose [12]. From the results, it can be seen that the higher the crumb rubber content in the asphaltic mixture, the mixture is less resistant to fracture.

Moreover, the finding for samples mixed with crumb rubber is different to the other sample variations. It can be seen for samples mixed with coconut fibre and Styrofoam, the higher the percentage of additives added, the higher the stability values at dry condition will be, which means the samples
were getting more stable. For the samples mixed with RAP, there was not much difference between the samples mixed with different percentages of RAP. Out of all samples, it can be seen that the samples mixed with RAP had the highest stability values.

![Graph](image_url)

**Figure 3.** ITS test results for all sample variations

The ITS values at dry and saturated conditions were used to calculate Tensile Strength Ratio (TSR) value, which is the ratio of the stability or the strength of a sample when the sample is dry to the stability or the strength of a sample when the sample has been immersed in the water bath for 24 hours at 60°C. The higher the TSR value, the higher the resistance to moisture the sample has, as it means there is less difference between the ITS values at dry and saturated states, and thus, the samples were not disturbed much by the presence of moisture. Figure 4 shows the results for TSR values for all sample variations. For the samples mixed with crumb rubber, RAP, and coconut fibre, it can be seen that the higher the percentage of crumb rubber, the higher the TSR value, which shows that the recycled material helps providing some resistance to water. For the samples mixed with Styrofoam, there is not much difference in TSR values as the percentage of Styrofoam increases. TSR values at figure 4 shows that replacing all coarse aggregate by RAP can increase the resistance of specimens when subjected to moisture.
4. Conclusions

There is a high demand in using alternative and more environmentally friendly materials in road maintenance projects. A number of studies has been done to evaluate the alternative materials that could be used, especially to reduce the demand for fresh aggregates. The research assesses the usage of four recycled materials to be used in asphaltic mixture, which are crumb rubber, RAP, coconut fibre, and Styrofoam. Based on the three tests conducted, which were Marshall, Cantabro Loss, and ITS tests, it can be concluded that to obtain maximum result the crumb rubber, RAP, coconut fibre, and Styrofoam, to be used at 3%, 100%, 0.6%, and 2.5%, respectively. The addition of the recycled materials can improve the density and the stability of the asphaltic mixture and the susceptibility to moisture. However, it is important to note the samples prepared were dense and had low void in mixture, which could potentially cause some workability issue when applying the mixture in field and create some pavement distresses, such as bleeding and over compaction on the asphalt mixture. For future research project, it is recommended that the aggregate grading is modified, e.g. by increasing the proportion of coarse aggregate, to increase the gap between aggregates, and hence, the asphaltic mixture will have a more desirable void content to improve the workability of the mixture.

References

[1] Taha R, Ali G, Basma A and Al-Turk O. Jan. 1999. Evaluation of Reclaimed Asphalt Pavement Aggregate in Road Bases and Subbases. Transp. Res. Rec. 1652, 1 p. 264–269.

[2] Hassan K E, Elghali L and Sowerby C R. 2004. Development of new materials for secondary and recycled aggregates in highway infrastructure.

[3] Syamsuwirman S. 2016. Study Penambahan Styrofoam Pada Perkerasan Asphalt Concrete Wearing Course (AC-WC), Universitas Andalas.

[4] Ariyapijiati R H, Hadiwardoyo S P and Sumabrata R J. Jun. 2017. Contributions crumb rubber in hot mix asphalt to the resilient modulus. AIP Conf. Proc. 1855, 1 p. 30005.

[5] Putri E E and Syamsuwirman S. 2016. Tinjauan Substitusi Styrofoam Pada Aspal Pen. 60/70 Terhadap Kinerja Campuran Asphalt Concrete - Wearing Course (AC-WC). J. Tek. Sipil 6, 1.

[6] Rif’an A. 2016. Pengembangan Campuran Split Mastic Asphalt Menggunakan Bahan Reclaimed Asphalt Pavement dan Ijuk. Universitas Muhammadiyah Surakarta.
[7] Chesner W H, Collins R J, MacKay M H and Emery J. User Guidelines for Waste and By-Product Materials in Pavement Construction.

[8] Al-Qadi I L, Elseifi M and Carpenter S H. 2007. Reclaimed Asphalt Pavement — A Literature Review, Urbana, IL.

[9] Wati W. 2015. Pengaruh Penambahan Bahan Alami Lateks (Getah Karet) terhadap Karakteristik Campuran Hot Rolled Sheet Wearing Course (HRS-WC), Bina Nusantara University.

[10] Badan Standardisasi Nasional. 1991. Campuran beraspal, Metode pengujian dengan alat Marshall.

[11] Nataadmadja A D, Prahara E, Setyandito O and Ananditha R W. Dec. 2019 Evaluation of moisture susceptibility of hot mix asphalt AIP Conf. Proc. 2202, 1 p. 20106.

[12] Adedimila A S. Sep. 1986. Technical Note. A Comparison of the Marshall and the Indirect Tensile Tests in Relation to Asphalt Mixture Design. Proc. Inst. Civ. Eng. 81, 3 p. 461–469.