Deformation of rutting due to temperature change from recycle of hot-mix asphalt with crumb rubber

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Abstract. The cover layer of the pavement can be functioned as a structural layer or non-structural layer. Improvement of road surface conditions is done by overlay with additional layers above it or stripping the surface layers of the road. Reclaimed Asphalt Pavement (RAP) or asphalt stripping results into a new problem of aggregate asphalt waste. Utilization of material from the pavement surface layer can reduce environmental pollution and can save maintenance cost. Research has been done by knowing the content of asphalt and gradation of aggregate from stripping asphalt through the extraction process. A few modified asphalts as Asbuton Retona Blend-55 (Asbuton-R) and fresh aggregates have been added to obtain the aggregate bitumen mixture on the specification type of Asphalt Concrete Wearing Coarse (ACWC) mixture. Crumb Rubber (CR) of used tire rubber has been added to the new aggregate and mixed with the old asphalt mixture, and then added asphalt modified Asbuton-R. Crumb rubber (CR) of 0.5%, 1%, 1.5% and 3% were added to each variation of asphalt content ranging from 1.5%; 2%; and 4%.

The result of the recycled aggregate asphalt mixture was tested with MarshaLL Standard and Marshall Immersions on the optimum Asbuton-R content. The deformation resistance of pavement mixture to weather changes has been simulated using Wheel Tracking Machine (WTM) at 26° C, 30° C, 35° C. The results showed that RAP content of more than 80% can still be utilized in the recycling process. The asphalt pavement mixture resistance to rutting deformation due to temperature change, with the addition of 1.5% of optimum Asbuton-R content has shown an increase.

1. Introduction
On roads who receive relatively heavy traffic loads, frequent road distress occurs. Road deteriorations are usually repaired by an overlay, this way causes the pavement to become thick and easy to damage the structure. Road pavement recycling technology becomes one of the prospective alternatives. The damaged paved layer was scrapped and crushed using a recycling machine. This scrapped material which is then called as Reclaimed Asphalt Pavement (RAP). Some agencies provide restrictions on RAP used percentages ranging from 10 to 30% in their regulations due to concerns over pavement performance [1]. Other studies can even maximize the use of RAP with warm mix recycled asphalt specimens were prepared with 100% RAP and different emulsion contents [2]. But not all applications of RAP usage can be maximally, depending on the type of mixture of recycled materials and the amount of material, due to factors such as source and replacement binding rates, the aging rate on recycled materials, and the proportion in the mixture influence the recycling dose [3].

The use of RAP can even be used for sub-base and has been observed that California Bearing Ratio (CBR) values of 100% RAP are in the range of 8% - 20%. It is observed from the previous study that
CBR values of 50% RAP + 50% Crushed stone aggregates with 2% cement is in excess of 100% [4]. This study investigated 20%-40% RAP content with additional crumb rubber (CR) against rutting deformation with temperature change. Deformation tested using a wheel tracking machine (WTM).

This recycling technology offers various advantages such as saving aggregate and asphalt needs, reducing fuel requirements and emissions of gas products. Regards to the utilization of RAP, this potential trend has become a major attractive solution to conserve energy and keep environmental sustainability [5].

Used tire waste in Indonesia is predicted to continue to grow in line with the growth of vehicle ownership which is marked by the increase in vehicle volume. The crumb rubber (CR) produced from scrap tires is generally used for the construction of asphaltic pavements. Usually crumb rubber is used in two ways for asphaltic pavement applications (i) dry process: where crumb rubber is mixed with aggregates first and then with asphalt binder for production of mixes, and in (ii) wet process: where crumb rubber is mixed with binder first, like polymer modified binder, and then used for preparation of mixes [6]. The use of CR as an additive material on asphalt mixture cannot be standardized because the microstructure of rubber asphalt may not be stable at elevated temperature, which could lead to separation of crumb and asphalt during storage [7].

Development of new technologies was always focused on increasing cost-effectiveness, but recently along with the economic effects environmental issues have been considered, such as reducing the negative impact on the environment in the production of materials [8]. This research objective is expected to know the performance recycle of hot mix asphalt against repeated load wheels of the vehicle due to temperature change, where the recycle of hot mix asphalt was added by crumb rubber additives. It inquired the contribution of the recycle hot mix asphalt and additives regarding with the effect on deformation of rutting. The use of additives is also intended to provide the asphalt mixture that is environmentally friendly, especially for the temperature change. A series of laboratory tests were conducted in sequences to determine the characteristics of RAP.

2. Material and Method
The RAP material is taken from the Jakarta Outer Ring Road-S Section (JORR-S) toll road segment taken in August 2017. The average maximum grain size is found about 9.5-12.5 mm. Asphalt RAP content is known by extraction using reflux apparatus as described in table 1.

| Information                | Weight (gr) extraction #1 | Weight (gr) extraction #2 |
|---------------------------|---------------------------|---------------------------|
| RAP before extraction     | 1000                      | 1000                      |
| Filter paper before extraction | 8.5                        | 10.29                     |
| RAP after extraction      | 935.5                     | 937                       |
| Filter paper after extraction | 12                         | 16.59                     |
| Total RAP after extraction | 939                       | 943.3                     |
| Asphalt                   | 61                        | 56.7                      |
| Asphalt content           | 6.1%                      | 5.67%                     |

The aggregate sieve analysis process is then performed using a sieve shaker with the results as described in table 2.

| Sieve | Diameter (mm) | Pass RAP | Based Indonesian Std. |
|-------|---------------|----------|-----------------------|
| 1     | 25.4          | 100      | 100 100               |
| 3/4   | 19            | 100      | 100 100               |
| 1/2   | 12.5          | 95.71    | 90 95                 |
2.1. Mix design and fresh aggregate adding

The addition of fresh aggregate is done to improve the gradation of RAP to be able to approach the aggregate provision of hot asphalt mixture based on Indonesian standard. The addition is done so that the aggregate size makes the curve line below the maximum standard and above the minimum standard. After the addition of aggregate for RAP weighing 1000 gr, obtained the formula of adding the size of aggregate with the size of pass 12.5 mm as much as 5 grams; addition of aggregate with sieve pass sizes 9.5 mm as much as 90 gr; the addition of aggregate with the size of pass sieve 2.36 mm as much as 10 gr and the addition of aggregate with sieve pass sizes 0.075 as much as 75 gr. The total weight of RAP aggregate after added fresh aggregate to 1123.3 gr. More details related to the design and the addition of aggregate described with the graph in figure 1.

![Figure 1. Aggregate gradation modified used for recycling hot-mix asphalt](image)

2.2. Buton Natural Asphalt (Asbuton)

BNA is produced by refining Buton Island rock asphalt to separate minerals and increase the bitumen content from 13–20% to 55–60% [9]. The BNA-R was used as an additive or modifier to modify the properties of base bitumen. BNA-R pulverized until a particle size smaller then mixed with asphalt Pen 60/70 at temperature of 140 °C while stirring at a speed of approximately 2000 rpm. The addition of BNA-R has reduced penetration and has increased the softening point and viscosity[10]. In this study used Asbuton Retona Blend-55 (Asbuton-R).

2.3. Experimental Design and Test Procedures

Testing in this study was conducted using RAP and CR with Asbuton-R with 60 penetration grades. The different forms of HMA were analyzed using the Marshall standard and WTM tests. Two types of samples were tested: RAP, and modified RAP+CR asphalt concrete with added asphalt content of 1.5% and CR content of 1%.
2.4. Marshall Stability
The Marshall test is performed at the standard and immersion condition. The Marshall test is performed on cylindrical specimens, 102 mm in diameter and 64 in height, at a temperature of 60 °C and rate of loading of 51 mm per minute.

Table 3. The Marshall test result

| CR Percentage (%) | Asphalt Percentage (%) | Average Thickness (mm) | Correction Factor | Marshall Stability (kg) | Marshall Quotient (kg/mm) |
|-----------------|-------------------------|------------------------|------------------|-------------------------|--------------------------|
| 1.0             | 1.5                     | 65.87                  | 0.945625         | 2239.16                 | 722.3091                 |
| 1.0             | 1.5                     | 65.97                  | 0.943750         | 2277.69                 | 679.9086                 |
| 1.0             | 2.0                     | 65.80                  | 0.946875         | 1983.41                 | 489.7314                 |
| 1.0             | 2.0                     | 66.68                  | 0.930313         | 2139.35                 | 638.6133                 |

From the marshall stability test results obtained that 1% CR addition and 1.5% asbuton Retona Blend-55 are the best addition as showing in table 3 and then the researchers made a WTM briquettes sample for hot mixture composition with 1% CR addition and 1.5% asbuton Retona Blend-55 addition. Wheel tracking machine apparatus used in this study displayed at figure 2, and then the WTM tested results are depicted in figure 3.
Figure 3 shows a RAP briquette sample that has been added a fresh aggregate of 20% and Asbuton weighing 1.5% after to testing WTM and figure 4 shows a modified RAP specimen that has been added CR 1% after a WTM test was performed.

3. Results and discussion

The curve illustrated in figure 5 were result of WTM at different test temperature of 26˚C, 30˚C, and 35˚C for hot mix RAP modified and hot mix RAP modified with CR addition. Shown clearly that the modified RAP plus CR as much as 1% and Asbuton as much as 1.5% has a relatively good strength against rutting deformation for temperatures of 26˚C and 30˚C as compared to not added CR. But when the given temperature is added up to 35˚C the sample decreases drastically at WTM test.

Many authors consider that permanent strain changes during loading cycles are divided into primary, secondary and tertiary zones [11]. The VESYS model was developed for rutting prediction models.

VESYS model: \[ \varepsilon_p(N) = \mu \cdot \varepsilon_r \cdot N^{-\alpha} \]  

Where; \( \varepsilon_p(N) \) is permanent or plastic strain due to a single load application, i.e., at \( N \)th application; \( \varepsilon_r \) is the elastic or resilient strain, generally assumed to be independent of load repetition \( (N) \); and \( \mu \) is the permanent deformation parameter, which represent the constant of proportionality between the permanent strain and the elastic strain and \( \alpha \) is a permanent deformation parameter indicating the rate of decrease as the number of load applications increases [11][10].

![Figure 5](image)

**Figure 5.** Test results showing rutting deformation for various temperature test conditions recycle of hot-mix asphalt and RAP with CR addition

With an empirical approach that connects between \( d_i / N_i \) and \( N_i \), is obtained function that can be written as:

\[ d_i = N_i \cdot a \cdot (N_i)^{-b} \]

The value of the coefficients “a” and “b” are the parameters of the recycle of HMA characteristics that can be identified through a series of WTM tests. The equation generated from the wheel tracking tests are summarized in table 4 below:
Table 4. The deformation equation generated from the WTM test

| Temperature | Core Material | Equation           |
|------------|--------------|--------------------|
| 26 °C      | RAP          | \( y = 0.0252x^{-0.33} \) |
|            | RAP+CR       | \( y = 0.2061x^{-0.738} \) |
| 30 °C      | RAP          | \( y = 0.3715x^{-0.737} \) |
|            | RAP+CR       | \( y = 0.5312x^{-0.628} \) |
| 35 °C      | RAP          | \( y = 0.4067x^{-0.552} \) |
|            | RAP+CR       | \( y = 0.0491x^{-0.298} \) |

Figure 6, 7 and 8, shows that the addition of temperature to the wheel tracking test will increase rutting deformation. Likewise, with the addition of CR to the RAP mixture which relatively increases the pavement quality so that the rutting deformation that arises becomes smaller.

Figure 6. Deformation curves with logarithmic scale at 26 °C temperature

Figure 7. Deformation curves with logarithmic scale at 30 °C temperature

Figure 8. Deformation curves with logarithmic scale at 35 °C temperature

From the results of the above tests it can be concluded that the recycle hot-mix asphalt is not recommended to be applied at high temperatures and the addition of CR is not too significant help when used at relatively high temperatures.

4. Conclusions
The use of additives to improve the performance of recycling hot-mix asphalt greatly affect the resistance of deformation of asphalt mixture hot mix asphalt (HMA). Asbuton blend-55 made from Asbuton semi extraction and crumb rubber can be used as a modifier of bitumen base of RAP mixture. In general, the ability of RAP with bitumen modification (Asbuton 1.5% and CR 1.0%) to withstand repeated loads is preferable when used at low temperatures, high-temperature use is not recommended.
for this mixture. Further research is needed so that the performance criteria of recycling hot-mix asphalt in permanent deformation as well as or even better than HMA.

Acknowledgements
This work is supported by Hibah PITTA 2018 funded by DRPM Universitas Indonesia No. 2531/UN2.R3.1/HKP.05.00/2018. And the authors are also grateful to Audy Dwi Putra and Fahmi Fajriansyah (student at Civil Engineering Department, Universitas Indonesia) for their assistance in obtaining the data.

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