Design mixed formula of hot mix asphalt mixture very thin overlay using crumb rubber

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Abstract. One of the technologies expected to improve the quality of flexible pavement is to use a modified asphalt mixture of Crumb Rubber (CR). The material can be used as a very thin added layer which is then called Very Thin Overlay Modified Crumb Rubber (VTO Mod-CR) and the functions as a leveling layer. This asphalt mixture is expected to have high durability and increase the age service life of flexible pavement. The aim of this study was to analyze the design mix formula (DMF) and the durability of the asphalt mixture. This research carried out variations of asphalt content i.e. 6.0%, 6.5%, 7.0%, 7.5% and 8.0% with each variation of 3 specimens for Marshall Test. Based on the DMF analysis results obtained optimum asphalt content of 7.00%, while the properties of the mixture in the form of bulk density of 2.240, VIM of 3.77%, VMA of 18.15%, VFA of 79.23%, Stability of 1049 kg, Flow of 3.47 mm, Marshall Quotient of 251 kg / mm, Bitumen Film Thickness 16.08 µm. The results of the analysis of the mixture properties have met specifications General of Highways, so it can be used as a reference for AMP. The BFT value obtained meets the minimum specification specifications of 16 µm, this shows that the resistance to water and oxidation is higher, so the pavement becomes durable.

1. Introduction
The first paragraph after a heading is not indented (Bodytext style). The flexible pavement construction so far has relied more heavily on new material and neglected the environmental issue [1-3]. Road pavement construction and reconstruction indicate a considerable consumption of valuable and non-renewable natural resources and, in particular, the component materials of asphalt mixtures [4-6]. On the other hand, the increasing need for transportation and technological advances that are always developing, the quality of transportation infrastructure is demanded to be more reliable to serve traffic, but must also consider environmental and economical aspects [7, 8]. In the last few decades, several developing countries have developed and implemented the innovative design of environmentally friendly asphalt mixtures, one of which is the asphalt modification crumb rubber technology [9-11]. Indonesia began to adopt the technology in 2012, while as a mixture the new asphalt began to be implemented in 2017 [12].
Asphalt Modification of Crumb Rubber (Asphalt Mod-CR) began to be the first choice as a binding material in the flexible pavement because it is believed to show excellent quality, high durability and a comfortable surface to cross [13-15]. Previous Research showed that having asphalt rubber mix resistance has better resistance to deformation [16]. Asphalt mixture of modified rubber powder or Crumb Rubber Modified (CRM) with a composition of more than 20% has a higher viscosity (viscosity), better flexibility (Marshall Quotient), increase anti-fatigue and anti-aging [17-19]. These aspects are very suitable to meet the needs of road infrastructure with flexible pavement construction such as in Indonesia which is a high-temperature tropical country [20-22].

Utilization of Asphalt Mod-CR can be used as a very thin overlay that also functions as a leveling wear layer as a leveling wear layer. VTO Mod-CR as a surface layer functioned as a wear out grading which aims to improve the surface level of the road, depending on the elevation of the rigid pavement surface below [23-25]. Hot mix with asphalt rubber has a very good structural value so that it can be applied with a thickness of 50% compared to conventional asphalt [26-28]. The implementation of VTO Mod-CR asphalt mixture starting from the production process, mixing, spreading to compaction requires special treatment compared to conventional asphalt in general [29-31]. In the production process, this asphalt mixture requires a higher mixing temperature than the ordinary asphalt mixture, so it requires fuels that are capable of producing high heat such as kerosene or gas [22, 32, 33]. The mixing process in the mixing unit or Asphalt Mixing Plant (AMP), is also a little longer to ensure that the asphalt mixture is really well mixed and evenly (homogeneous). The consequence of this is that production costs will also increase. Because the thickness of the very thin layer and homogeneity of the mixture must be maintained so that segregation does not occur at the time of the laying, the temperature at the time of the laying and compaction of the mixture must continue to be controlled. Thick beds that range from only 2.5 cm cause the layer to be very sensitive to the ambient temperature which results in a very rapid fall in the temperature of the mixture. Spraying water on the compactor wheel which is usually done in the compaction process must be avoided. The use of compactors with rubber tires is also not permitted because it will cause a tiring trail. Inadequate temperature [34] during spreading and compaction will result in the mixture clumping and segregation so that when compacted it will not get maximum density. Even if compaction continues when the temperature of the mixture has exceeded the minimum limit of compaction temperature, cracking or rupture of the layer will occur. Another significant difference with conventional asphalt is in the manufacture of Mod-CR asphalt Design Mix Formula (DMF) especially in the aspect of the number of collisions of test specimens. The number of collisions of Asphalt Concrete Base, AC Binder, and AC Wearing according to SNI is 2 times 75 collisions back and forth. Meanwhile, modified Crumb Rubber heat asphalt mixture used in VTO (Very Thin Overlay) is 2 times 50 alternating collisions. This is due to the consideration and calculation that the largest aggregate size used is 12.5 mm and will be spread with a very thin layer thickness which can cause the temperature of the mixture to tend to fall faster. The number of collisions 2 times 50 for the VTO is already considered quite perfect in the laboratory as a reference and comparison of the implementation in the field later.

According to DGoH (2015) [35], the value of the degree of density in the field must comply with the specification requirements of at least 98% of laboratory density. The minimum thickness of the layers is 2.5 cm, causing the layer to be very sensitive to the ambient temperature. Thus, based on the background that has been described, it is necessary to study the process of making the design mix of VTO Mod-CR asphalt mix formulas. This study aims to determine the design mix formula (DMF) of VTO Mod-CR asphalt mixture which is used as a reference or reference prior to the implementation of production in AMP and analyze the durability of the asphalt mixture.
2. Methods
The main material used in this research is coarse aggregate, fine aggregate and crumb rubber asphalt. Coarse aggregates and fine aggregates (stone ash), originating from the village of Ngargosari, Ampel, Boyolali which are produced at PT. Anugrah Batu Alam (ABA). Modified crumb rubber asphalt is made from a mixture of asphalt oil and crumb rubber (rubber powder from used tires), originating from PT. Bintang Djaja, Cilacap.

The DMF creation begins by testing the material properties which serve to determine the character and quality of the material to be used in the mixture. Furthermore, mixed test specimens are made with variations in asphalt content to determine the optimum asphalt content (OAC). Investigation of the properties of the mixture was carried out by the Marshall Test method. Whereas to obtain the value of BFT (Bitumen Film Thickness) obtained based on aggregate gradation data. The outlines of the stages of making DMF VTO Mod-CR is presented in Figure 1. The number of test specimens for Marshall Test is 3 test pieces with 5 variations of asphalt content namely 6.0%, 6.5%, 7.0%, 7.5%, and 8.0%. Optimum asphalt content is used to determine the initial level of asphalt in laboratory planning. Research conducted in the laboratory is used to obtain asphalt contents used in planning flexible pavement in the field. The asphalt content of each plan differs due to variations in grain size in each

![Flowchart of DMF creation](image)

**Figure 1.** Flowchart of DMF creation
plan. The optimum asphalt content of the plan (Pb) is obtained by the following equation:

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

where:

- \( P \) = Middle/ideal asphalt content, percent by weight of the aggregate mixture plus asphalt
- \( \text{CA} \) = % aggregate retained sieve No. 8
- \( \text{FA} \) = % aggregate passing sieve No. 8 and retained No. 200
- Filler = % aggregate minimal 75% passing sieve No. 200
- \( K \) = Constanta (0.5-1 for Laston; 2-3 for Lataston; and 1-2.5 for another mixture).

The BFT value is associated with the flexibility and resistance to water which of course will produce high pavement durability as well. To calculate the BFT, it is necessary to first find the total aggregate surface area which can be calculated based on combined aggregate gradation data and aggregate surface area factors (Surface Area Factors, SAF). Next, the BFT of the asphalt mixture on DMF is determined by the following formula:

\[ T = \frac{b}{100 - b} \times \frac{1}{pb} \times \frac{1}{SAF} \]  

where:

- \( T \) = Bitumen Film Thickness (mm)
- \( b \) = Asphalt content (%)
- \( pb \) = Specific gravity of asphalt
- SAF = Surface Area Factors (m²/kg)

3. Analysis and discussion

VTO Mod-CR DMF data processing consists of aggregate gradation analysis, Marshall Test and maximum bulk density \( (G_{mm}) \) mixture, which can finally be determined by the OAC of the mixture. From the results of the gradation analysis, it can be determined the aggregate proportion of each faction by graphical and trial error. The aggregate percentages of Hot Bin I, Hot Bin II and Fine Filler (FF) are entered into trial errors in such a way that they are in accordance with specifications. From the calculation results obtained the proportion of each faction is Hot Bin I by 28%, Hot Bin II by 70%, and Fine Filler by 2%. The results of combined aggregate gradations that have been carried out in the form of Figure 2 shows that the gradations have met the required specifications.

![Figure 2. Combined gradation graph](image-url)
After finding the estimated optimum asphalt content (7.00%), then the maximum bulk density mixture ($G_{mm}$) can be performed as presented in Table 1.

**Table 1. Maximum bulk density mixture calculation results ($G_{mm}$)**

|                          | Sample 1 | Sample 2 |
|--------------------------|----------|----------|
| Bottle weight + sample (gr) | a        | 2126.4   |
| Bottle weight (gr)        | b        | 626.4    |
| Sample weight (gr)        | c = a - b| 1500.0   |
| Bottle weight + water (gr)| d        | 344.8    |
| Bottle weight + water + sample (gr) | e   | 1200.4   |
| Fill in the example (cm$^3$) | f = c + d - e | 644.4  |
| Specific gravity          | g = c / f| 2.328    |
| Water temperature (°C)    | h        | 25       |
| Temperature correction    | i        | 1.000    |
| Specific gravity (corrected) | G = g x i | 2.328   |
| Average specific gravity  |          | 2.329    |

Before conducted the trial mix at AMP, the analysis of the mixture was carried out based on 5 variations of the asphalt content of the Marshall test, to obtain the stability, flow, and Marshall Quotient. As for the volumetric mixture, the results of the examination are bulk density, voids in the mix (VIM), voids in mineral aggregates (VMA), and voids filled with asphalt (VFA). The results of testing the properties are presented in Figure 3 until Figure 9.

Bulk density is the ratio of the weight of the mixture in the air to the volume, including the air cavity, divided by the weight of the water content at the same temperature. The value of the density of the mixed bulk indicates the density of a mixture because this value is obtained from the ratio between the weight and volume of the mixture. From Figure 3, it can be seen that the specific gravity. The highest bulk is at 7% asphalt content of 2.240, which means that mixes with asphalt content below and above 7% have less density.

![Figure 3. The relationship between asphalt content and bulk density](image)

The range of VIM is 3% - 5% so that the VTO Mod-CR asphalt mixture as a surface layer is more impervious to water and air, which can cause oxidation and asphalt to become brittle. Based on Figure 4 above, the asphalt content that meets the VIM value is 6.2 - 7.7%.
VMA is the void in mineral aggregate found in the aggregate granules in the asphalt mixture that has been compacted and effective asphalt, expressed in percent of the total volume of the mixture. VMA value will increase along with the increase of asphalt blanket or if the aggregate used is graded open. The test results in Figure 5 shows that the VMA value tends to increase along with the increase in asphalt contents. In this test all mixes with asphalt content of 6% to 8% meet the specified specifications (minimum of 17%).

VFA is void filled with asphalt in the mixture after undergoing the compaction process expressed in percent of the cavity between the aggregate grains (VMA) but does not include asphalt absorbed by the aggregate. Factors that can affect VFA include asphalt content, aggregate gradation, compaction energy, and asphalt heating. From the test results shown in Figure 6, the VFA value tends to increase along with the increase in asphalt contents. In this test all mixes with asphalt content of 6% to 8% meet the specified specifications (minimum 66%).

Stability is the ability of the pavement layer to accept the burden of traffic without experiencing permanent deformation such as waves, grooves (rutting), or experiencing bleeding. The stability value is influenced by asphalt cohesion, asphalt content, internal friction, interlocking properties of aggregate particles, surface shape and texture and aggregate gradation. The test results show that the stability value obtained tends to increase to the optimum limit and then decreases (can be seen in Figure 7).
The optimum stability value occurs at 7% asphalt content which is equal to 1049.5 kg. Flow is an implementation of the flexibility characteristic of the mixture produced. Flow value is influenced by asphalt content, aggregate distribution, and compaction temperature.

Figure 8 shows the value of flow with variations in asphalt contents. The test results show that the more asphalt content in the asphalt concrete mixture, the greater the value of flow. This is because the addition of asphalt contents makes the mixture more plastic so that the deformation due to load increases. In this test all mixes with asphalt content of 6% to 8% meet the specified Flow value specifications i.e., min. 3 mm.

MQ is the quotient between Stability and Flow. MQ value in Figure 8 shows the flexibility of the mixture that is the greater the MQ value in a mixture, the more rigid (if too rigid tends to crack easily) the mixture, as well as the smaller the MQ value, the degree of flexibility and plasticity (too flexible tends to be less stable) the mixture will get bigger. From the test results obtained the MQ value at 7.00% asphalt content of 251 kg / mm, indicating that the VTO Mod-CR asphalt mixture has fairly good flexibility. Based on the Marshall and volumetric test results of asphalt mixture in Figure 2 through Figure 9, then used as a basis for finding the optimum asphalt content, shown in Figure 10.

Based on the analysis results, the OAC value was obtained at 7%.

The DMF recapitulation results shown in Tables 2 through Table 4 are a mixed draft plan which will then be applied at AMP. Table 2 shows the composition of the mixture, while Table 3 is the total aggregate composition in the mixture before asphalt is added. Table 4 is the result of combined aggregate grading analysis.
Table 2. DMF mixture composition

|                         | Result | Result |
|-------------------------|--------|--------|
| Design of asphalt content | 7.00 % |        |
| Hot bin I               | 26.0 % | 28.00 %|
| Hot bin II              | 65.1 % | 70.00 %|
| Filler cement           | 1.90 % | 2.00 % |
| Total                   | 100 %  | 100 %  |

Table 3. DMF combined gradation

| Sieve size | Combined gradation (%) | Specification (%) |
|------------|-------------------------|-------------------|
| Inch       | mm                      |                   |
| 1/2"       | 12.7                    | 100.0             | 100 |
| 3/8"       | 9.5                     | 88.60             | 75-100 |
| #4         | 4.8                     | 50.38             | 35-55 |
| #8         | 2.4                     | 28.79             | 20-35 |
| #16        | 1.2                     | 20.99             |       |
| #30        | 0.60                    | 17.99             |       |
| #50        | 0.30                    | 12.01             |       |
| #100       | 0.15                    | 6.88              |       |
| #200       | 0.075                   | 3.66              | 2-8   |

Table 4. Recapitulation of the properties of the DMT VTO Mod-CR mixture

|                         | Result | Specification | Units |
|-------------------------|--------|---------------|-------|
| Optimum asphalt content | 7.0    | -             | %     |
| Bulk density            | 2.240  | -             | -     |
| Void in Mix (VIM)       | 3.54   | 3.0 – 5.0     | %     |
| Void in Mineral Aggregate (VMA) | 18.15 | > 17 | %     |
| Void Filled with Asphalt (VFA) | 80.51 | > 66 | %     |
| Stability               | 1049.5 | Min 600       | Kg    |
| Flow                    | 4.23   | Min 3         | Mm    |
| Marshall Quotient       | 251    | -             | kg/mm |
| Bitumen Film Thickness  | 1.08   | Min 16        | µm    |

VTO Mod-CR asphalt mixture has advantages in aspects of flexibility, durability, and adhesive compared to conventional asphalt. The analysis shows that the BFT value of asphalt VTO Mod-CR mix results of AMP trial mix of 16.89 µm has met the minimum specification requirements of 16 µm, this shows that the resistance to water and oxidation is higher so pavement becomes durable.

4. Conclusions

Based on the analysis, it can be concluded that the OAC is 7.00%, so that the composition of the mixture with asphalt content is 26.0% for a hot bin I with a screen size of 5 mm and 65.1% hot bin II with a screen size 1/2" and 1.90% cement filler. The DMF asphalt mixture properties were obtained 2.240 of bulk density values, 3.77% of VIM, 18.15% of VMA, 79.23VFA, 1049 kg of Stability, 3.47 mm of Flow, 251 kg/mm of Marshall Quotient, and 16.08 µm BFT. The composition and properties of the mixture have been obtained that meet the specifications so that it can be used as a reference for
mixing at AMP. The BFT has fulfilled the minimum specification requirements of 16 μm, this shows that the resistance to water and oxidation is higher so that the pavement becomes durable

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