Design and Properties of Thin Surfacing Hot Mix Asphalt Containing Crumb Rubber as Partial Aggregate Replacement

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Abstract. Road damage caused as a result of the traffic load and environment. One method to improve the road condition is from an overlay. But the new layer on the top of the pavement structure is thick enough and elevate the surface of the pavement, so it will cause some impact on the user safety and engineering. The use of a thin layer of hot mix asphalt is an alternative to anticipate the thickness problem. Crumb rubber is a waste material that has a flexible nature, these materials are used as an aggregate replacement in the hot mix asphalt thin layer. The research was conducted to find the optimum bitumen content and optimum crumb rubber content on asphalt mixtures by the Marshall procedure. Finally, it was concluded that the addition of crumb rubber in a thin layer of hot mix asphalt indicates the better the interlocking between aggregates so that gave the better Marshall stability, the higher the flow rate, the lower the marshall quotient, reduce the void ratio. The results show that the addition of crumb rubber content as an aggregate replacement leads to the use of less optimum bitumen content.

1. Introduction
The use of a thin surfacing of hot mix asphalt is one alternative that can be used to anticipate the problems of pavement surface elevated due to conventional overlay. Thin surfacing hot mix asphalt is a technology that is being developed as a preventive maintenance effort and resurfacing of the surface damaged pavement. The surface layer has a thickness that ranges between 25-40 mm and it is expected to solve problems such as fretting (loose of aggregate), more resistant to water penetration (impermeability) and increasing the roughness (skid resistance) [1-4]. The use of crumb rubber as a mixture of asphalt is also expected to reduce the use of excessive petroleum asphalt, so as to save the asphalt which is the natural resource that could not be renewable. Crumb rubber can be obtained easily because the residual material of the tire retreading industry, so indirectly to make an effort to recycle unused materials [5]. Previous researches have been conducted to assess the compatibility of using crumb rubber in the design of road materials [6-8]. Further research is required regarding the addition of crumb rubber in the design of hot asphalt mixture thin surfacing material with expectations to obtain maximum results and appropriate to the Indonesian circumstances in so it can be practically implemented.

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2. Experimental

The materials used for this research are coarse aggregate, fine aggregate, filler, asphalt 60/70 pen and crumb rubber. The properties of coarse aggregate and fine aggregate are presented in Table 1.

| No | Type of Test         | Coarse aggregate | Fine aggregate |
|----|----------------------|------------------|----------------|
|    |                      | Results          | Specification  | Results          | Specification  |
| 1  | Adsorption (%)       | 2.512            | max. 3.0       | 2.093            | max. 3         |
| 2  | Bulk density (gr/cc) | 2.514            | min. 2.5       | 2.665            | min. 2.5       |
| 3  | SSD Density (gr/cc)  | 2.577            | min. 2.5       | 2.707            | min. 2.5       |
| 4  | Apparent Density (gr/cc) | 2.683       | –              | 2.881            | –              |

The properties of 60/70 pen asphalt were tested using Indonesian Standard Test and presented in Table 2.

| No | Type of Test          | Value | Unit   | Specification |
|----|-----------------------|-------|--------|---------------|
|    |                       |       |        | Minimum      |
|    |                       |       |        | Maximum      |
| 1  | Penetration           | 69.7  | 0.1 mm | 60           |
| 2  | Ductility             | >150  | cm     | 100          |
| 3  | Softening Point       | 48    | Celcius| 48           |
| 4  | Flash Point           | 257.5 | Celcius| 200          |
| 5  | Burning point         | 325   | Celcius| 200          |
| 6  | Specific Gravity      | 1.038 | g/cc   | 1            |
| 7  | Affinity              | 98    | %      | 95           |

The Standard manufacture Job Mix Asphalt aggregate substitute referring to Standard Specification Construction of Transport Systems (North Carolina Department of Transportation), while the testing of the specimen based on standards issued by the Asphalt Institute Superpave Series 1 (SP -1) and adopting of the method standardized by the Directorate General of Highway in the form of National Indonesian Standard (SNI).

This research was conducted by testing asphalt as a preliminary test and testing of the mixture of the characteristics of Marshall. Marshall test conducted to obtain the density, porosity, stability, flow and Marshall Quotient can then be calculated and obtained their binder content and optimum levels of addition of crumb rubber. The gradation of thin surfacing is presented in Table 3 [1].

| No | Sieve Size (mm) | Specification | Median | Gradation Used |
|----|-----------------|---------------|--------|----------------|
| 1  | 3/4" (19 mm)    | 100           |        |                |
| 2  | 1/2" (12.7 mm)  | 85 – 100      | 92.5   | 92.65          |
| 3  | 3/8" (9.51 mm)  | 60 – 80       | 70     | 69.30          |
| 4  | No.4 (4.76 mm)  | 28 – 38       | 33     | 33.62          |
| 5  | No.8 (2.38 mm)  | 19 – 32       | 25.5   | 25.16          |
| 6  | No.50 (0.297 mm)| 8 – 13        | 10     | 10.60          |
| 7  | No.200 (0.074 mm)| 4 – 7        | 5.5    | 5.68           |

The Crumb rubber used in this study was obtained from the retreading industry in Solo, Indonesia. The size of crumb rubber used is passed through sieve # 50 and retained by sieve # 100 and has a specific gravity of 1.058 g/cc. Figure 1 shows the crumb rubber used in this investigation.
3. Results and Discussion
The results of the investigation are presented in term of the influence of percentage crumb rubber as an aggregate replacement on the Marshall and volumetric properties and the influence of crumb rubber content on the optimum bitumen content of the thin surface hot mix asphalt.

3.1. The influence of crumb rubber aggregates replacement content on the Marshall and Volumetric Properties
The Optimum bitumen content was determined by performing a test Marshall. Marshall test performed based on the estimated level of asphalt while the asphalt content variation of 3.5%, 4%, 4.5%, 5% and 5.5%. It also determined the optimum level of crumb rubber to be used in research using the total volume ratio of aggregate to be used. Before the Marshall test done, first tested the Volumetric include measurement of diameter, thick and heavy in the air, then do the calculations to obtain density values, SGmix, and porosity. Marshall then new testing and obtained the value of stability, flow and Marshall Quotient. Of the value - the value can be determined mix of the best properties or the optimum bitumen content. The volumetric and Marshall properties of hot mixture thin surfacing asphalt with crumb rubber partial aggregate replacement are presented in Table 4.

The influence of bitumen contents and crumb rubber content variations are presented in Figure 2, it shows that the addition of crumb rubber in the mixtures gave influence on the value of stability. It is seen that the stability has increased with the addition of crumb rubber by 0.3% and 0.5% are 742.22 kg and 766.540 kg, respectively. This happens because the greater the crumb rubber contained in the mixture to make power tie between aggregate the better because crumb rubber will serve as a and additional binder to obtain better interlocking and bonding between aggregate and bitumen hence increasing the value of stability.

The influence of aggregate replacement by crumb rubber on the volumetric properties is illustrated in Figure 3. It could be seen that the addition of crumb rubber influence on the void ratio of the mixture. Porosity is affected by the density and the specific gravity of the mixture. It is seen that the addition of crumb rubber decreases the void ratio. This suggests that increased levels of crumb rubber by 1% to 0.5% resulted in an air cavity contained in the mixture decreases due to that the crumb rubber will serve as a binder that filled the voids as well as assist the bonding between the asphalt aggregate. This also can improve the strength of the mixture.
Table 4. The results of Marshall test at various bitumen and rubber content.

| Bitumen Content | Stability (kg) | Porosity (%) | Flow (mm) | Bulk Density (g/cm³) | Marshall Quotient (kg/mm) | Rubber Content (%) |
|-----------------|----------------|--------------|-----------|----------------------|--------------------------|--------------------|
| 3.5             | 410.804        | 11.747       | 1.833     | 2.06                 | 223.83                   |                    |
| 4               | 638.134        | 9.019        | 2.117     | 2.10                 | 306.59                   |                    |
| 4.5             | 750.458        | 8.315        | 2.267     | 2.09                 | 330.00                   | 0.5                |
| 5               | 631.445        | 5.043        | 1.600     | 2.14                 | 398.17                   |                    |
| 5.5             | 402.362        | 5.109        | 1.467     | 2.11                 | 277.22                   |                    |
| 3.5             | 489.395        | 12.135       | 1.567     | 2.04                 | 322.15                   |                    |
| 4               | 624.003        | 9.415        | 2.333     | 2.12                 | 274.90                   |                    |
| 4.5             | 766.540        | 8.710        | 2.400     | 2.10                 | 320.18                   | 0.3                |
| 5               | 552.027        | 5.447        | 2.200     | 2.09                 | 161.53                   |                    |
| 5.5             | 428.861        | 5.509        | 2.033     | 2.11                 | 210.52                   |                    |
| 3.5             | 421.221        | 12.524       | 1.600     | 2.04                 | 258.64                   |                    |
| 4               | 554.779        | 9.811        | 2.050     | 2.10                 | 268.93                   |                    |
| 4.5             | 716.528        | 9.105        | 1.900     | 2.10                 | 374.54                   | 0.1                |
| 5               | 594.695        | 5.852        | 2.100     | 2.10                 | 286.66                   |                    |
| 5.5             | 512.953        | 5.909        | 1.850     | 2.10                 | 279.21                   |                    |
| 5               | 515.301        | 12.718       | 2.250     | 2.09                 | 244.93                   |                    |
| 5.5             | 612.879        | 10.010       | 2.200     | 2.08                 | 286.34                   |                    |
| 6               | 742.223        | 9.302        | 2.183     | 2.11                 | 352.46                   | 0                  |
| 6.5             | 479.091        | 6.054        | 2.167     | 2.06                 | 220.85                   |                    |
| 7               | 388.374        | 6.109        | 2.167     | 2.09                 | 179.86                   |                    |

Figure 2. The Stability of thin surface asphalt mixture at various bitumen and rubber contents
Figure 3. The porosity of thin surfacing hot mixture at various crumb rubber aggregate replacement

3.2. The influences of crumb rubber aggregate replacement on the optimum bitumen content

The optimum bitumen content of asphalt level that will produce the best characteristics in terms of the nature of the value of stability in an asphalt mixture. The bitumen content to be used in calculating the level of asphalt manufacture the next test object. To search for the value of the optimum bitumen content calculated the regression equation bitumen content relationships with stability as presented in Table 2. From the chart it can be concluded that the decreased use of crumb rubber asphalt penetration 60/70 along with increasing levels of CR is used. This happens because with greater levels of CR contained in the mixture to make asphalt easier to bind the aggregate in the mix because CR will function as a binder. The correlation between crumb rubber content and optimum bitumen content could be expressed as $y = 12.96x^2 - 8.692x + 5.656$ with $R^2 = 0.873$ as presented in Figure 4. It can be seen that the use up to 0.3% by weight of crumb rubber on the pavement mix has the effect on reducing the use of conventional petroleum bitumen hence become more environmentally friendly infrastructure construction.

Figure 4. The influenced of partial aggregate replacement by crumb rubber on the optimum bitumen content
4. Conclusion
The addition of crumb rubber in thin surfacing hot mixture asphalt demonstrates increasing the value of Marshall Stability, Marshall Flow and decreasing the value of Marshall Quotient, porosity, hence giving better performance of the mixture. In addition, from the correlation analysis between the percentage of aggregate replacement by crumb rubber and the optimum bitumen content has the effect on reducing the optimum bitumen content, so reducing the use of conventional petroleum bitumen and become more environmentally friendly infrastructure construction.

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