Contributions Crumb Rubber in Hot Mix Asphalt to the Resilient Modulus

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Abstract. Pavement on the structure of the surface layer receives direct load from the vehicles. Road surfaces are designed to withstand the wear from vehicle loads. Therefore, we need a way to improve the durability of the pavement. Road damage may reduce the life of roads and increase the maintenance costs. The retention rate of road surface material is affected by the environmental conditions, one of them is temperature. To overcome the issues related to temperature, material additives are added to the asphalt mixture. These additive materials would change the binding properties of bitumen and the characteristics of strain and stress before the damage due to repeated traffic loading. Crumb rubber (CR) is a type of polymer additives and thermoplastic elastomers are obtained from scrap tires and rubber waste that is utilized in order to preserve the environment. This study investigated the contribution of the crumb rubber in terms of the value of resilient modulus and resistance to deformation. Hot mix asphalt used was asphalt Pen 60/70, coarse aggregate, fine aggregate and filler. Crumb rubber was made from scrap tire rubber, in the form of fine powder with sieve no. 30 (0.6 mm). CR additive was added to the base asphalt at several rates of 5\%, 10\%, 15\%, and 20\% at a temperature of 177\degree C. The test data used the indirect tensile test with a tool UMATTA at temperatures of 25\degree, 35\degree, and 45\degree C. The test results showed that the levels of crumb rubber on the asphalt decreased the penetration rate, increased the bitumen softening point, and improved the resistance to permanent deformation. The addition of additive materials was evidenced to improve the penetration index, reduce the temperature sensitivity, and increase the viscosity. Subsequently, it can extend the temperature range of viscoelasticity. The contributions of crumb rubber in hot mix asphalt included the increase of the recoverable deformation and the decrease of the value of resilient modulus. This study indicated that by the addition of crumb rubber, the pavement material becomes more elastic, so it can reduce the level of damage in the form of cracks on roads, but it also declines the ability of the pavement to withstand the loads.

INTRODUCTION

A variety of causes can lead to the road damage including over loading and low quality materials. To improve the ability of pavement materials, additive material added to the bitumen, one of them is crumb rubber. The mixture can increase the performance by enhancing the rigidity as well as the resistance to permanent deformation and fatigue.

Resilient modulus is one the important properties in the mechanistic analysis of pavement response under dynamic traffic loads. Resilient modulus is also used in the evaluation of the materials quality. In addition, indirect tensile strength is also an important parameter to assess the characterization of resistance to the failure of asphalt concrete due to the tensile stresses.

The physical interaction between the crumb rubber (CR) and bitumen physically occurs when through diffusion, CR absorbs a portion of the aromatic fraction of bitumen that leads to the swelling of CR particles. Effective size of particles will depend on the temperature. The elastomer interface of CR is clear and the holes are widely spread before the mixture, whereas, after the mixture, the interface is not clear and the holes will disappear [1]. Crumb rubber can be used for a variety of civil engineering projects including in rubberized asphalt pavements, flooring for playgrounds, and sport stadiums in the form of shock absorbing mats, paving blocks, and roofing materials [2].
Wang [3] explicated the reason of the addition of crumb rubber can improve the anti-fatigue properties of asphalt mixtures, which is the elements of crumb rubber powder such as carbon black that can improve the asphalt binder or the mixture of asphalt against the aging. Subsequently, it would increase the film thickness of asphalt on the surface of the aggregate and then improve the aging resistance of asphalt mixtures.

Rubber powder waste has a significant impact in reducing the depth of asphalt rutting at a particular temperature, in which a mixture of asphalt that contains 10% of rubber powder waste was evidenced to have a better performance at high temperatures. In addition, the addition of rubber powder additive reduces the thermal sensitivity of asphalt mixtures that will increase the resistance to permanent deformation [4].

The addition of crumb rubber on high modulus asphalt mixtures also increases the stiffness, which brings a positive effect in terms of bearing and stress distribution capacities. Nevertheless, when these materials are subjected to high strain, this characteristic can exert a negative effect in terms of fatigue resistance that can induce a premature failure of this type of mixtures when the deflections in the pavement layers are high [5].

Kim [6] claimed that CRM mix wet processed is more powerful than the dry mixture in SD and ITS, which indicates that the process of wet manufacturing method is better than the dry process in terms of resistance to deformation at high temperatures and tensile strength at ambient temperature.

Furthermore, Cong [7] reported an increase in the viscosity as the result of an increase in particle size as well as the flow behavior which is more likely to turn into a non-Newtonian fluid. In addition, the increase of temperature results in a significant reduction of viscosity, in which a larger particle size seems to hamper the viscosity. Liang [9] suggested the addition of CR asphalt produced a tremendous increase in the viscoelastic and viscosity characteristics in compared to those of base asphalt. As a result, it is expected that an increase of resistance to permanent deformation occurs on the road with CR modified bitumen.

Previous researches showed that the asphalt surfaces with and without the addition of low content of rubber in binder were evidenced to have insignificant difference in term of sound. Acoustic monitoring by a semi-anechoic chamber (CPX-method) showed a significant reduction in noise (about 2.5 dB (A) to 80 km / h), which is associated with high levels of incorporation CR to mix gradation gap. Acoustic perform during service life, a higher content of CR significantly reduced noise pollution in urban areas, while variation of 2.5 dB (A), similar in terms of traffic, approximately halved the volume of traffic [8].

This study investigated the performance of hot mix asphalt against repeated load wheels of the vehicle, where the hot mix asphalt was added by crumb rubber additives. It inquired the contribution of the hot mix asphalt and additives regarding with the effect on the resilient modulus of pavement materials. 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 was conducted in sequences to determine the characteristics of hot mix asphalt.

**MATERIALS AND METHODS**

**Aggregates**

The material aggregate consisted of the course, medium, and fine aggregate with the largest size of 19 mm and the dense grading for AC-WC (asphalt concrete-wearing course).

**Binder**

The samples of asphalt mixture were prepared by using two different types of binder. The base binder with the penetration grade of 60/70 from Shell and Crumb rubber modified bitumen were selected for this study. To prepare the CR modified bitumen, the asphalt binder was heated at 177 °C in temperature and the CR powders (5%, 10%, 15%, and 20% by weight of 60/70 bitumen) were added gradually into the bitumen in a high shear mixer at the speed of 700 rpm until reaching a homogeneous blend[10], with the characteristics as shown in Table-1 and Table-2.

**Crumb Rubber (CR)**

The increasing number of vehicles has increased the number of waste tires of vehicles. The utilization of waste tires included a process to form them into new materials, e.g., rubber powder. The utilization of scrap tires on roads was initiated by Charles MacDonald in the 1960s when he used waste tires for maintenance works in urban areas.
Tire rubber has an advantage as an additive in asphalt cement for repairing potholes [11]. In this study, crumb rubber was made from scrap tire rubber, in the form of fine powder by using sieve no. 30 (0.6 mm).

### TABLE 1. Properties of base asphalt binder (Pen 60/70)

<table>
<thead>
<tr>
<th>Bitumen property</th>
<th>Standard</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penetration at 25°C</td>
<td>ASTM-D5</td>
<td>0.1mm</td>
<td>69.3</td>
</tr>
<tr>
<td>Softening point</td>
<td>ASTM-D36</td>
<td>°C</td>
<td>49.7</td>
</tr>
<tr>
<td>Flash point</td>
<td>ASTM-D92</td>
<td>°C</td>
<td>254</td>
</tr>
<tr>
<td>Ductility at 25°C</td>
<td>ASTM-D113</td>
<td>cm</td>
<td>&gt;140</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>ASTM-D70</td>
<td>g/cm³</td>
<td>1.023</td>
</tr>
<tr>
<td>Loss on heating (TFOT)</td>
<td>%</td>
<td></td>
<td>0.03</td>
</tr>
<tr>
<td>Penetration after TFOT</td>
<td>ASTM-D5</td>
<td>%</td>
<td>63.3</td>
</tr>
<tr>
<td>Penetration Index</td>
<td></td>
<td></td>
<td>-0.295</td>
</tr>
</tbody>
</table>

### TABLE 2. Properties of base asphalt modified (CR additive)

<table>
<thead>
<tr>
<th>Binder property</th>
<th>Standard</th>
<th>Unit</th>
<th>Percentage of CR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penetration at 25°C</td>
<td>ASTM-D5</td>
<td>0.1mm</td>
<td>66.1 63.7 61.7 58.2</td>
</tr>
<tr>
<td>Softening point</td>
<td>ASTM-D36</td>
<td>°C</td>
<td>52.25 53.25 54 55</td>
</tr>
<tr>
<td>Flash point</td>
<td>ASTM-D92</td>
<td>°C</td>
<td>256 282 246 246</td>
</tr>
<tr>
<td>Ductility at 25°C</td>
<td>ASTM-D113</td>
<td>cm</td>
<td>74.4 54.5 49.6 42.3</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>ASTM-D70</td>
<td>g/cm³</td>
<td>1.033 1.04 1.046 1.052</td>
</tr>
<tr>
<td>Loss on heating</td>
<td>%</td>
<td></td>
<td>0.17 0.2 0.22 0.33</td>
</tr>
<tr>
<td>Viscosity at 135°C</td>
<td>AASHTO</td>
<td>cST</td>
<td>525 750 875 1383</td>
</tr>
<tr>
<td>Penetration after TFOT</td>
<td>ASTM-D5</td>
<td>0.1mm</td>
<td>59.6 57.4 53.6 51.7</td>
</tr>
<tr>
<td>Penetration Index</td>
<td></td>
<td></td>
<td>-0.295 -0.239 -0.198 -0.183</td>
</tr>
</tbody>
</table>

### Resilient Modulus

Resilient modulus is the elastic modulus that is used based on the elastic theory. It is well known that most of paving materials are not elastic, hence, they will endure some permanent deformations after each load application. However, if the load is insignificant in comparison to the material strength and is repeated for a large number of times, the deformation under each load repetition is nearly completely recoverable and proportional to the load and can be considered as elastic [12]. The elastic modulus based on the recoverable strain under repeated load is called the resilient modulus (MR) that is formulated as follows:

$$MR = \frac{\sigma_d}{\varepsilon_r}$$  \hspace{1cm} (1)

Resilient modulus test is non-destructive test and the same sample can be used for a variety of tests under different load and environmental conditions. Specimens for asphalt mix used for the compression test are usually 4 inches (102 mm) in diameter and 8 inches (203 mm) in height, while the indirect tensile test requires 4 inches (102 mm) in diameter and 2.5 inches (64 mm) in thickness.

In this research, the method to test the resilient modulus was the indirect tensile test (ASTM D7369 - 11). The above asphalt mixture was subjected to the test. Cylindrical specimens of 4 inches (102 mm) in diameter and of 63 mm in height were used in this indirect tensile test. Indirect tensile test on resilient modulus was subjected to haversine loading shape. The test had 250 ms time of loading with rest period of 900 ms, and three different temperatures (i.e., 25°, 35°, and 45° C).
RESULTS AND DISCUSSION

Effect of crumb rubber additive in asphalt characteristics

The test results showed that the level of crumb rubber on the asphalt had caused a decrease of penetration rate, an increase of bitumen softening point (Table 1 & 2), and an improvement of resistance to permanent deformation. The addition of the additive materials improved the penetration index and reduced the sensitivity to temperature and significantly increased the viscosity of the binder that extended the temperature range of viscoelasticity (Fig. 1).

![FIGURE 1. Viscosity of the binder.](image)

Effect of temperature on the recoverable deformation

The addition of crumb rubber additive improved the ability of the pavement mixture that was imposed by repeated load and the horizontal deformation returned to normal. It showed the mixed material becomes more elastic, so as to prevent the occurrence of cracks in the pavement. Fig. 2 demonstrated the increased temperature from 25°C to 45°C led to the increased number of recoverable horizontal deformation that was allegedly due to thermoplastic properties of the asphalt material. With the addition of crumb rubber additive, the number of recoverable horizontal deformation increased significantly with the highest value with CR level of 10%.

![FIGURE 2. Recoverable Horizontal Deformation.](image)

The addition of crumb rubber from the amount of 5% to 20% resulted in an increased number of recoverable horizontal deformation. Fig. 2 figured out a temperature of 45°C had a higher influence on the addition of crumb
rubber additive. Subsequently, the figure also demonstrated that the addition of crumb rubber on pavement material was more effective at low temperature, which was 35° C and below.

**Effect of crumb rubber content on the resilient modulus**

The results of the indirect tensile test with UMATTA tool showed that the value of resilient modulus decreased significantly in linear to the increased level of crumb rubber at a fixed binder content. This was due to the reduced amount of bitumen content that was replaced by the increase amount of crumb rubber. Resilient modulus value declined by 50% from 3000 MPa to 1500 Mpa in the addition of crumb rubber of 10% in content. As illustrated in Fig. 3, the diverse binder contents of 5.5%, 6.0%, and 6.5% generated a slight increase in the value of resilient modulus.

![FIGURE 3. Influence of CR additive on Resilient Modulus.](image)

Based on the analysis, the values of resilient modulus between the low and high temperature were significantly different, which indicated that the hot mix asphalt without any additives was not resistant to the changes of temperature. Meanwhile, the mixture contained additives was more resistant to the effects of temperature changes.

![FIGURE 4. Influence of Temperature on Resilient Modulus.](image)

Figure 4 demonstrated the increased percentage of additive concentration resulted on the declined value of resilient modulus. It can be seen the increased temperature of the specimens from 25° C to 45° C resulted in the precipitous decrease of resilient modulus value of the specimen without additive (steep graph slope), while the
values of resilient modulus of specimen with the addition of crumb rubber had moderate slope. It suggests that the mixture of pavement with the addition of crumb rubber additive is more resistant to the temperature changes.

**CONCLUSIONS**

The use of crumb rubber as an additive material in hot mix asphalt was generated from scrap materials from tire rubber as an effort of environmental preservation. It was expected that this additive would improve the characteristics of mixed materials pavement. Based on the results obtained from this study, several conclusions can be drawn:

1. The addition of crumb rubber improved the penetration index, thus, reduced the sensitivity to temperature and significantly increased the viscosity of the binder that could extend the temperature range of viscoelasticity.
2. The values of resilient modulus between the low and high temperature were significantly different, which indicated that the hot mix asphalt without any additives was not resistant to the changes of temperature, while the mixture contained additives was more resistant to the effects of temperature changes.
3. Contributions of crumb rubber in hot mix asphalt is to increase the number of recoverable horizontal deformation, which means the hot mix asphalt will be more elastic in enduring repeated loads, thereby it will reduce the number of cracks. However, the values of resilient modulus decrease. Contributions of crumb rubber in asphalt hot mix obtain an effective value in the combination of 10% of CR and an air temperature of 35° C and below.

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**REFERENCES**
