RESEARCH PAPER:

Study of Crumb Rubber Modified Local Asphalts Using Classical Tests

Diyar Nadhim Hasan Shwan*,1, Aso Faiz Saeed Talabany1

1 Department of Civil Engineering, College of Engineering, Salahaddin University-Erbil, Kurdistan Region, Iraq.

ABSTRACT:
The rapid growth of population and industrialization levels around the world requires higher number of vehicles for transportation and better road qualities, on one hand, on the other hand this growth causes a huge number of scrap tires. Incorporating scrap tires into the asphalt pavements will help in saving the environment beside improving some of its properties and recycle the scrap tires. This study investigates the effect of Crumb Rubber Modifier (CRM) on the asphalt properties using classical tests. Different percentages of CRM by weight of the asphalt was added to three locally produced asphalts of different sources and grades. The results of this study show that higher CRM contents lead to decrease penetration and ductility values, while it causes increase of the softening point, elastic recovery and penetration index. Higher softening point and elastic recovery indicate better resistance against rutting and high temperature deteriorations, higher penetration index indicates lower temperature susceptibility and better road life performance.

KEY WORDS: Modified Asphalt; CRM; Recycled tire; Classical Asphalt tests.
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1. INTRODUCTION:
Crumb Rubber is a general term that describes scrap tires that have been cut and reduced in size into fine granular particles for use in asphalt pavements as a modifying material. In the last decades, the rapid growth of industrialization levels and population have been caused in increased demand of transportation particularly higher number of vehicles in the developing and industrialized countries. This growth, in addition to other waste products, generates a huge number of used tires every year. According to ETRMA (2011), about 1.5 billion tires are sold globally every year. Finally, most of these tires fall into the category of scrap tires. One of the worrying environmental issues is how to deal with these used tires.

In General, the purpose of adding CRM to asphalt is to enhance some of its properties such as lower temperature susceptibility, better fatigue and permanent deformation resistance. The enhancement of the CRM asphalt properties depends on the interaction process between the asphalt and the CRM to a great extent, where a viscous gel is formed due to the swelling of the CRM particles, resulting in a higher viscosity of the CRM asphalt.

The CRM properties that can affect the interaction process are chemical composition, production process, specific surface area and particle size (Heitzman, 1992). CRM can be obtained from tires by two major methods: (1) Ambient, is a method of processing scrap tires where the tire is processed or ground at the normal room temperature using special tools; (2) Cryogenic, is a grinding method in which liquid nitrogen of temperature less than -80°C is used to freeze the scrap tires until the rubber is brittle, then a hammer mill is used to shatter the frozen rubber into small particles. The CRM produced
with this method has smoother particles and relatively smaller surface area.

The reaction between the asphalt and the CRM is made up of two simultaneous processes: absorption of the oily materials in the asphalt into the polymeric chains of the rubber, on one hand, on the other hand, partial digestion of the CRM into the asphalt. (Navarro et al., 2007, TREDREA, 2006) mentioned that after adding 15% of CRM to the asphalt, only a range of 2 to 4 percentage is dispersed or dissolved in the asphalt.

CRM reaction with asphalt is a time-temperature dependent process. If the time is too long or the temperature is too high, the swelling will continue to a point where, swelling is replaced by devulcanisation/depolymerisation because of long exposure to high temperatures which causes the dispersion of the CRM into the asphalt (Presti, 2013).

The swelling process of CRM particles governs the improvements of the asphalt properties. Due to the absorption of the maltenes components of the asphalt, CRM particles can swell three to five times its original size (Peralta et al., 2010, Vonk and Bull, 1989). This leads to increase the asphaltenes proportion in the asphalt binder, consequently increase its viscosity.

The mechanism nature via which the interaction between the CRM and the asphalt happens has not been completely characterized. Heitzman (1992) stated that the interaction is a non-chemical reaction which doesn’t cause the dissolving of the rubber particles in the asphalt binder. Instead, the absorption of the oily phase materials and swelling of the CRM particles lead to decrease the free space between the rubber particles, as a result increase the viscosity of the asphalt. Bahia and Davies (1994) stated that the higher viscosity of the asphalt cannot be only resulted from the presence of swollen rubber particles.

(Mashaan et al., 2011, Mashaan and Karim, 2013) showed that the increase in the mixing temperature leads to higher softening point, Brookfield Viscosity, complex shear modulus and elastic recovery values, whereas the longer mixing time has no significant effect on CRM modified asphalt properties in the case of 30 and 60 minutes. (Moreno et al., 2011, Shen and Amirkhanian, 2005) indicated that the mixing time shows an insignificant difference in the optimal binder content selection.

Mashaan et al. (2011) studied the effect of different CRM contents on the rheological, physical properties and rutting resistance of CRM modified asphalts. The results of the study showed that higher CRM content leads to decrease the penetration, ductility and phase angle values, whereas causes to increase the elastic recovery, complex modulus, loss modulus and storage modulus. Increased elastic recovery indicates a better resistance against rutting deformation which occurs in asphalt pavements due to high traffic volume and loading.

Lee et al. (2008) studied the performance properties of CRM modified asphalts with different CRM contents and processing methods using SUPERPAVE rheological tests of asphalt. They used CRM from passenger car scrap tires processed with two different methods, one source used cryogenic grinding method and the other used ambient grinding method. The results of the study show that the ambient grinding method is more effective in decreasing the temperature susceptibility and increasing the viscosity while there is no statistically significant difference between these two methods in the fatigue cracking and m-value (slope of stiffness curve at 60 seconds in Bending Beam Rheometer test).

Sebaaly et al. (2003) conducted a study to evaluate the rheological behavior of CRM modified asphalts at low temperatures. The study included three different sizes of CRM, four asphalt types and three CRM contents. The results of the study showed that CRM size has no significant effect on the low temperature properties of the asphalt. Also, he motioned that some combinations of CRM content and size may either improve or jeopardize the low temperature performance grade of the asphalt.

The objective of this study is to discover the effect of adding four different percentages of CRM on the properties of locally produced asphalts of two different sources and two different grades using classical asphalt tests.

2. MATERIALS AND METHODS

2.1. Materials

2.1.1. Asphalt binders:

In this Study three types of locally produced asphalts are used, two asphalts with different grades (source A grade 40-50 and source B grade 50-70) from Lanaz refinery which is located in Erbil, and the third type of asphalt (source C grade 50-70) from Phoenix refinery which is located in Arbat-Sulaymaniya. Table 1 shows the
characteristics of the three original asphalts from sources A, B and C.

### Table 1 Properties of the original asphalts.

<table>
<thead>
<tr>
<th>Test Method</th>
<th>Source A*</th>
<th>Source B*</th>
<th>Source C**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penetration at 25 °C</td>
<td>ASTM D5</td>
<td>43</td>
<td>55</td>
</tr>
<tr>
<td>Ductility at 25 °C</td>
<td>ASTM D113</td>
<td>&gt;150 Cm</td>
<td>&gt;150 Cm</td>
</tr>
<tr>
<td>Elastic Recovery at 25 °C</td>
<td>ASTM D6084</td>
<td>9 %</td>
<td>8 %</td>
</tr>
<tr>
<td>Softening Point</td>
<td>ASTM D36</td>
<td>52 °C</td>
<td>49 °C</td>
</tr>
<tr>
<td>Penetration after RTFO test at 163 °C</td>
<td>ASTM D2872</td>
<td>20</td>
<td>24</td>
</tr>
<tr>
<td>Loss on heat</td>
<td>ASTM D2872</td>
<td>0.63 %</td>
<td>0.84 %</td>
</tr>
<tr>
<td>Flash Point</td>
<td>ASTM D92</td>
<td>320 °C</td>
<td>270 °C</td>
</tr>
</tbody>
</table>

*From Lanaz refinery.
**From Phoenix refinery.

#### 2.1.2 Crumb Rubber

The CRM used in this study is from truck scrap tires obtained from a special factory from Baghdad-Iraq that uses special tools and devices to cut and shred scrap tires into small particles at normal room temperature. Figure 1 shows microscopic image (40x) of CRM modified asphalt for different CRM contents for source C (Phoenix refinery, grade 50-70), in which the CRM particles are shown in the form of black spots. Table 2 shows the gradation of CRM used in this study and CRM from two other studies for the purpose of comparison (Lee et al., 2008, Shen et al., 2009).

![Microscopic image of CRM modified asphalt](image)

**Figure 1:** Microscopic image (40x) of CRM modified asphalt with different CRM contents for Source

<table>
<thead>
<tr>
<th>Sieve Size (mm)</th>
<th>This Study</th>
<th>Lee et al. 2008</th>
<th>Shen et al. 2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>0.425</td>
<td>-</td>
<td>83</td>
<td>60.8</td>
</tr>
<tr>
<td>0.3</td>
<td>72</td>
<td>74</td>
<td>19.3</td>
</tr>
<tr>
<td>0.18</td>
<td>-</td>
<td>42</td>
<td>13.1</td>
</tr>
<tr>
<td>0.15</td>
<td>24</td>
<td>9</td>
<td>11.1</td>
</tr>
<tr>
<td>0.075</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Table 2 Gradation of CRM.**

#### 2.2 Experimental Works

The asphalt batches preparation was made by mixing the original asphalts with different CRM percentages (0.5, 10, 15 and 20% by weight of the asphalt). The mixing process continued for 30 minutes at 180 °C with 950 rpm mixer speed. For the three asphalt types and the five different CRM contents, the total number of prepared asphalt batches in this study is 15. For each test a minimum of three samples are tested. The flow chart in Figure 2 summarizes the experimental works.

### Figure 2: Flow Chart of Experimental Work Procedure

3. **RESULTS**

The classical asphalt test results were used to show the effect of CRM content on the basic properties of asphalt are shown in Figure 3 through Figure 7 and Tables 3 and 4.

The results of penetration, ductility, softening point, elastic recovery, flash point and RTFO are measured directly from the tests, while the penetration index results are calculated using equations (1) and (2) from penetration value at 25 °C and the softening point (Ehinola et al., 2012).

\[
PI = \frac{20(1-25A)}{(1+50A)} \quad \ldots \ldots (1)
\]

\[
A = \frac{\log(\text{pen at } 25 ^\circ \text{C}) - \log 800}{25-\text{ASTM Softening Point}} \quad \ldots \ldots (2)
\]

\[PI= \text{Penetration index.}
\]

\[A= \text{Temperature susceptibility.}\]
4. DISCUSSIONS

4.1 Penetration

The penetration value decreases by the increasing of CRM content (see Figure 3 (a)). The reduction in the penetration value is resulted from the stiffening of the asphalt due to the absorption of the light materials by CRM particles and the digestion of CRM into the asphalt. The percentage...
of reduction in the penetration value after adding 20% of CRM is equal to 51%, 53% and 57% for sources A, B and C, respectively. This high reduction in the penetration value should be considered before using such modified asphalts in road pavements, because if the asphalt is too stiff causes thermal cracking of the pavement in cold weathers.

The statistical analysis shows that the correlation coefficients between CRM content and penetration value for sources A, B and C are equal to -0.89, -0.89 and -0.86 respectively.

The penetration results of this study have a similar trend to the results of studies conducted by other researchers (Mashaan et al., 2011, Nejad et al., 2012, Paulo and Jorge, 2008).

4.2 Softening Point

The results show that the effect of adding CRM differs according to the source of the asphalt. As seen in Figure 4, there is almost a linear increase of the softening point by incorporating and increasing the CRM content for the three sources of asphalt. The regression formulas for sources A and B show that for every 1% increase in CRM content, the softening point increases about 1°C degree, while for source C, the softening point increases about 1.5°C degree for every 1% of CRM added. The correlation coefficients between CRM content and softening point for sources A, B and C are equal to 0.99, 0.99 and 0.99, respectively.

Similar to this study, other studies show that the softening increases by increasing the CRM content (Dantas Neto et al., 2003, Mashaan and Karim, 2013, Nejad et al., 2012). Higher softening points indicate stiffer asphalts having the ability to improve its elastic deformation recovery, in addition, the higher the softening point indicates the better rutting resistance of the binder.

4.3 Penetration Index PI

As Figure 5 indicates, the penetration index increases by increasing the CRM content. The PI value for 0% CRM content of the sources A, B and C are approximate values, while after adding 20% of CRM the PI values reach 0.88, 1.3 and 2.58 for sources A, B and C, respectively. This means that CRM content has a greater effect on source C than sources A and B.

The higher penetration index means that the asphalts have less temperature susceptibility, asphalts with less temperature susceptibility are more resistant against low temperature cracking and rutting (Nejad et al., 2012). The correlation coefficient values for the sources A, B and C are equal to 0.96, 0.98 and 0.98, respectively.

4.4 Ductility

Ductility test provides a measure of tensile properties of asphalt. It is a measure of the elongation in centimeters of a standard specimen of asphalt before breaking at a temperature of 25°C. As illustrated in Figure 6, the ductility test loses about 90% of its value in a sudden decrease from 150 cm to 15 cm after adding 5% of CRM to sources A and B, and loses 93% of its value in a sudden decrease from 120 cm to 9 cm for the same CRM content for source C. The results show that CRM contents higher than 5% have no significant effect on ductility values. This dramatic decrease is resulted from the absorption of the oily materials in the asphalt by the CRM particles. The statistical analysis shows a correlation coefficient of -0.70, -0.72 and -0.70 for sources A, B and C, respectively.

The results of this study and Nejad et al. (2012) show a sudden decrease in the ductility value due to the incorporation of CRM into the asphalt, while Mashaan et al. (2011) shows that increased CRM content causes a gradual decrease in the ductility value.

4.5 Elastic Recovery

Figure 7 shows the effect of CRM content on elastic recovery for the three asphalt sources. The elastic recovery increases by increasing the CRM content. The elastic recovery of the three sources of asphalts almost has the same trend and behavior by increasing the CRM content. The elastic recovery at 20% CRM content has approximate values for sources A, B and C, which is about 80%. Statistical analysis shows that CRM content has a high correlation coefficient of 0.92, 0.95 and 0.90 with the elastic recovery for asphalt sources A, B and C, respectively.

Asphalt is a viscoelastic material; higher values of elastic recovery indicates that the asphalt has a better ability to recover its original shape after the application of loads. Higher values of elastic recovery mean a better resistance against rutting deformation and fatigue cracking. The results of this study have a corresponding trend to
the results of studies conducted by (Mashaan et al., 2011, Nejad et al., 2012).

4.6 Flash Point

According to ASTM D92 (2016) Flash Point “is the lowest temperature of the test specimen at which application of an ignition source causes the vapors of the test specimen to ignite under specified conditions of test”. This test covers the safety concerns against fire occurring of asphalt while heating at mix plant, spreading and compaction stages. Table 3 shows that the flash points are according to the Iraqi and ASTM standards (>232 °C).

The test of flash point was made for CRM contents of 0%, 5% and 10% because for higher CRM contents, the high temperatures caused to introduce bubbles on the surface of the sample and prevented the flash occurring.

4.7 Penetration After Rolling Thin Film Oven Test (RTFO)

Figure 3 (b) shows the penetration values after short term aging by RTFO test. The penetration decreases after the short term aging as a result of the RTFO test conditions. The RTFO test simulates the aging of the asphalt binder at mix plant, in this test the asphalt is subjected to a temperature of 163 °C and oxidation by hot airflow for 85 minutes that causes the loss of the light materials through volatilization. The results of the penetration for the original and RTFO aged asphalts shows that the penetration Aging Ratio (PAR) decreases by increasing the CRM content.

4.8 Loss On Heat

Table 4 shows the percentages of loss on heat of the asphalt binders due to the volatilization of the light materials in the RTFO test. The results show that CRM content has no obvious effect on loss on heat percentage.

5. CONCLUSIONS

From the results of adding CRM to three types of asphalt of different sources and grades, it can be concluded that:

1. The results of the three asphalt sources have similar trends by increasing the CRM content in penetration, ductility and elastic recovery tests, while the CRM content has a greater effect on Source C than Sources A and B in softening point test and penetration index values.

2. The penetration value has an inverse relationship with the CRM content in the asphalt, in which the penetration values for original asphalt decreases gradually, losing about 50% of its original value at 20% CRM content. The penetration of RTFO aged asphalts also decreases by increasing the CRM content, losing about 25% of its original value at 15% CRM content. The CRM content has a greater effect on the original asphalt than the RTFO aged asphalt due to the hardening of the asphalt and volatilization of its light materials.

3. Adding 20% CRM to the asphalt causes a dramatic decrease in the ductility property of the asphalt and losing about 90% of its value, whereas leads to increase its elastic recovery property to about 80%, which indicates a higher ability of the asphalt to recover its original shape after deformations due to high traffic volume and loading.

4. Asphalts modified with CRM have lower temperature susceptibility and better resistance of rutting and high temperatures due to the higher softening point and penetration index.

5. According to the results of this study, CRM has no obvious effect on flash point and loss on heat test results.

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