Full Length Research Paper

Contribution of Crumb Rubber in the Aging Process of Asphalt Concrete

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Received 27 June 2014; Accepted 15 August 2014

Abstract. Implementation of sustainable solutions in the road construction industry is considered as one of the major research topics worldwide. The impact of aging process on the properties of asphalt cement and asphalt concrete was investigated using both of short and long-term aging. Scrap tire rubber was introduced into asphalt cement to modify its physical and rheological properties. Two percentages of crumb rubber (8 and 16) percent by weight of asphalt cement have been tried to modify the properties of asphalt cement, and to investigate its contribution in the aging process. Such modified asphalt was implemented in the construction of asphalt concrete. Marshal, Resilient Modulus, and tensile properties of rubber-modified asphalt concrete were tested and compared with different aging periods and with that of reference mix. The results show that aging for 7 hours of asphalt cement, make the asphalt stiffer, that lead to decreased penetration by an average value of (47.24%), ductility (49.6%) and increased softening point (10.75%) and creep stiffness (79.25%). It was concluded that 8% of crumb rubber is able to overcome the negative impact of short and long term aging on overall asphalt cement and asphalt concrete properties, and improves the rutting resistance at 1000 repetition by (32.4 % and 57.3%) for short and long term aging respectively.

Keywords: Asphalt concrete; Aging; Scrap tire rubber; Tensile strength; Resilient Modulus

1. INTRODUCTION

One of the worst problems that meet asphalt during its service life is the "aging" problem. Aging causes stiffening and the asphalt become brittle which leads to a higher potential for fatigue and thermal cracking. Aging of asphalt pavements typically occurs through oxidation of the asphalt and evaporation of the lighter maltenes from the binder. This inevitably results in cracking in the pavement structure (Hachiya et al., 2003). Aging of asphalt mixtures is a very complex mechanism with reversible and mostly irreversible changes in physicochemical and mechanical properties. In a mechanical way, aging increases viscosity, softening point and the complex modulus, while it decreases penetration and phase angle. In a physicochemical way, aging changes the chemical composition of asphalt cement. The addition of crumb rubber could decrease the negative impact of aging process on overall properties of asphalt concrete (Sarsam, 2007).

Pasquini et al. (2012) studied gap graded Asphalt Rubber Asphalt Concrete (ARAC) for wearing course to carefully assess durability aspects and prepare dense graded asphalt concrete for wearing courses. The results show an increase in the Indirect Tensile Stiffness Modulus (ITSM) because of long-term aging of the ARAC mixture in comparison with that of the dense-graded reference mixture investigated in the same test conditions. Othman (2006) performed a comparative study on cyclic thermal aging between a conventional and an asphalt rubber mixture. It was stated that the asphalt rubber material exhibits superior fracture resistance to a conventional mix. The objective of this work is to investigate the role of crumb rubber in the aging process of asphalt cement and asphalt concrete. The construction of roads is one of the most material demanding industries in the world with great economic as well as environmental impacts. Significant efforts are seen in terms of recycling and reuse of pavement materials. These efforts are strong and are beginning to be part of the industry processes and practice (Sarsam, 2013). The objectives of this work were to study the implementation of sustainable solutions in the road industry, and to verify the possibility of using scrap tire rubber in asphalt concrete production. The contribution of such crumb rubber (which is considered as waste material) in the aging process of asphalt concrete was investigated. Reusing of the waste material such as scrap tire rubber in road construction could be beneficial in improving the
roadway materials quality, enhancing the elastic properties of asphalt cement, and reducing the impact of waste material on the environment.

2. MATERIALS CHARACTERISTICS

2.1. Asphalt cement

Asphalt cement was obtained from Nasiria oil refinery; the physical properties are listed in table 1.

2.2. Aggregates

Crushed quartz Coarse and fine aggregates were obtained from Nibai quarry; this aggregate is widely used in local asphalt paving, their physical properties are listed in table 2.

2.3. Mineral filler

Ordinary Portland cement from Tasluga factory was introduced as filler; table 3 shows major physical properties.

2.4. Crumb rubber

The crumb rubber produced by mechanical shredding at ambient temperature was obtained from tires factory at AL-Najaf governorate. This type is recycled from used tires. Table 4 presents its grain size distribution.

3. TESTING PROGRAM

3.1. Preparation of Rubber Modified Asphalt Cement

Rubber Modified asphalt is prepared using the wet process. Asphalt cement was heated to a 150 °C, and then blended with crumb rubber of two different percentages, (8 and 16 % by weight of asphalt cement). It was mixed in the laboratory using special manufactured mixer at a blending speed of 1500 rpm and elevated temperatures (185°C) for 60 minutes to promote the chemical and physical bonding of the components. During the blending process, the crumb rubber swells and softens, as it reacts with the asphalt, bubble formation was also noticed.

The asphalt cement and rubber modified asphalt samples were tested for physical and rheological properties such as Penetration, Softening Point, Ductility, Bending Beam Rheometer (BBR), surface free energy, stiffness modulus, penetration index PI, flexural creep stiffness of binder in the range of 30...
MPa to one GPa. At -18 °C. The thin-film oven test (TFOT) has been used for subjecting asphalt cement to age hardening process to simulate hot mix plant and placement conditions (short-term aging). Four aging periods of (2, 3, 5 and 7 hour) have been used to evaluate the physical and rheological properties of asphalt and rubber modified cement. The same physical and rheological properties were determined after aging. Fig.1 shows the crumb rubber sample, while fig. 2 shows the mixer implemented.

### 3.2. Preparation of asphalt concrete

The aggregates were separated to different sizes by sieving; Coarse and fine aggregates were recombined with mineral filler to meet the specified gradation shown in table 5. The combined aggregate was then heated to a temperature of (160 °C) and the asphalt cement was heated to a temperature of (150 °C) to produce a kinematic viscosity of (170±20) centistokes. Then, asphalt cement was added to the heated aggregate to achieve the desired amount, and mixed thoroughly by hand for 2 minute until all aggregate particles were coated with asphalt cement.

### 3.3. Short term aging

The loose asphalt concrete mix was placed in a pan, spread to an even thickness of 30 mm. The mixture in pan was placed in the conditioning oven for 4 hours at a temperature of 135 °C and the loose mix was shacked every 60 minutes to maintain uniform conditioning. After 4 h, it was removed from the forced-draft oven. The conditioned mixture was compacted by Marshall Hammer. This procedure was carried out in accordance with AASHTO R30. The same procedure was repeated by placing the loose mixture in oven for 8 hours to verify the impact of increasing the aging period. Such verification could simulate the field conditions when delay in the transportation of asphalt concrete occurs. Short-term aging process simulates aging of HMA that occurs during mixing, transporting, and compaction of asphalt concrete.

### 3.4. Long term aging

The long-term aging process simulates aging of HMA that occurs during the pavement service life, it was conducted after subjecting the loose asphalt concrete mix to 4 or 8 hours short-term aging. The loose mixture was compacted by Marshall Hammer using 75 blows on each side of the specimens. The specimen in mold was left to cool to room temperature for 24 hours and then it was withdrawn from mold by using sample extractor. The prepared Marshal specimens were conditioned into the oven for 48 or 120 hours at a temperature of 85 °C. This procedure was carried out in accordance with AASHTO R30.

The effect of aging periods on the properties of asphalt concrete at optimum asphalt content such as Marshall Properties, indirect tensile strength at 25 °C and 40 °C, Resilient Modulus and resistance to permanent deformation was evaluated.

<table>
<thead>
<tr>
<th>Table 5: Grain size distribution of asphalt concrete</th>
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</thead>
<tbody>
<tr>
<td>Sieve size (mm)</td>
</tr>
<tr>
<td>% finer by weight</td>
</tr>
<tr>
<td>SCRUB 2007 Specifications</td>
</tr>
</tbody>
</table>

**Fig. 1:** Crumb rubber

**Fig. 2:** Developed mixer
4. DISCUSSION OF TEST RESULTS

4.1. Effect of rubber and Aging on physical properties of Asphalt Cement

The penetration test was performed on both virgin and aged asphalt cement (after Thin Film Oven Test) at each aging time. Penetration test results at various aging times are presented in Figure 3. In general, as aging time increases the penetration decreases since asphalt cement became harder. The reduction in penetration at (3) hr. aging time is 28.9%. At (7) hr. aging, penetration becomes 48.9%. Such result correlates with those of (Al-Jumaily 2007). When Crumb rubber was added to the asphalt cement in percentage of (8 and 16% by weight of asphalt cement), it is noticed that the penetration decreases as rubber content and aging time increases, this agrees well with (Mashaan et al., 2011) finding. The percent losses in penetration at (3) hr. aging time is 21.6% for 8% crumb rubber and 18.2% for 16% rubber content. At (7) hr. aging, the penetration decreased by 43.2% for 8% crumb rubber and 45.5% for 16% rubber content as compare with modified asphalt cement before aging.

Softening point values increase with aging time as indicated in fig.4. When Crumb rubber was added to asphalt cement, the softening point increases as rubber content increases, such results agree with (Mashaan et al., 2011) and (Osman & Adam 2012) findings. The ductility of asphalt cement without additive was (+100 mm). It can be noticed from fig.5 that the ductility values decrease due to the increase in aging time, such behavior may be related to oxidation and loss of volatiles that increase when aging time increase. Such result agrees with (Al Jumaily, 2007) finding. When Crumb rubber was added to asphalt cement by 8%, it was noticed that the ductility decreases. When such percentage was duplicated, ductility was decreased but the variation in such reduction in ductility was not significant with aging time, such result agrees with (Mashaan et al., 2011) findings. The 16% rubber gave lower ductility than 8% rubber.

The low temperature behavior of asphalt can be characterized by the Bending Beam Rheometer (BBR) test. Fig.6 shows that creep stiffness values increases with increment of aging time. The increase in creep stiffness refers to the fact that aging process converts the asphalt consistency to very hard and brittle material. After adding rubber, the creep stiffness lower than that of virgin asphalt, this agrees with (Sarsam and Lafta, 2014), and (Bahia & Davies, 2012) findings. After aging the modified asphalt, the creep stiffness increased at lower rate when compared to virgin asphalt. This reduction in creep stiffness as compare with virgin asphalt may be related to the fact that crumb rubber is helpful in increasing the elasticity of asphalt binder during aging process.
4.2. Effect of rubber and Aging on Rheological Properties of Asphalt Cement

The Paving asphalts have penetration index PI value between (-2) and (+2) which exhibits normal susceptibility to temperature which is the rate at which the consistency of asphalt cement changes with a change in temperature.

The stiffness modulus was determined using shell nomograph at temperature of 60 °C, using a single loading time of 0.02 second, which is related to the typical traffic speed (50–60 kph); as suggested by Strategic Highway Research Program (SHRP), (Sarsam, 2006). Table 6 shows that the stiffness modulus of asphalt cement increases with increasing aging time and rubber content. This increment in
binder stiffness may be related to the age hardening which releases volatile component of the asphalt cements, resulting in mass loss and a stiffening effect. On the other hand, the chemical reaction between rubber molecules and asphalt will exhibit stiffening effect.

Surface free energy of asphalt binder is related to the work of cohesion within the binder and the work of adhesion between binder and aggregate. The influence of aging time and rubber content of asphalt cement on surface free energy is illustrated in Tables 6. The surface free energy is 26.342 ergs/cm². After 7 hr. of aging process, the surface free energy decreases to 23.03 ergs/cm². When adding 8% crumb rubber, the surface free energy decreased to 22.00 ergs/cm² as compare with unmodified asphalt cement. After duplicating the rubber content, the surface free energy decreased to 17.97 ergs/cm². It is important to realize that surface energy measurements reflect surface chemistry, which can differ substantially from bulk properties. Such result agrees with (Cheng et al. 2002); (Little and Bhasin, 2006); (Wei and Zhang, 2010) and (Sarsam and Azawee, 2013) findings, that aging reduces the surface free energy of asphalt binder significantly.

4.3. Effect of rubber and Aging on Marshall Properties

Fig.7 shows the effect of short and long-term aging periods on Marshall stability, and it can be observed that the short and long term aging of asphalt mixture have increases the Marshall Stability values. The Marshall stability after 8 hr. short aging is higher than that of virgin mixture by 42.2%. In addition, 8 hr. aging shows higher stability than that of 4 hr. Such increment may be related to the fact that due to aging, the viscosity increases thus leading to increase the strength of bond between the components of asphalt concrete. It can be observed that short-term aging of asphalt mixture for 8 hr. has higher stability when compared to aging of the asphalt mixture at 4 hr.

In the case of long-term aging of 5 day, the stability increases by 61% as compare with virgin mix. Such variations may be attributed to the loss of asphalt binder volatiles. Such result agrees with (Al-Jumaily, 2007) findings. When adding rubber to asphalt mixture by 8%, it could be observed that the stability increased by 24.35%. After aging process, it was found that the stability increased by 13%, 19.4% as compared with virgin and modified asphalt mixture respectively. After 5 day long-term aging, the Marshall stability of modified mixture gives higher stability than short term aging. The stability also increases by 60% as compared with modified virgin asphalt.

When duplicating crumb rubber percentage, the Marshall stability is lower than that of 8% crumb rubber initially, but still shows higher stability than that of virgin mixture in aged and unaged processes. At 8 hr. aging, it was found that 16% crumb rubber shows higher stability than 8% rubber. At 8 hr. aging, the stability is almost equivalent to that at 2 day aging. Results indicate that the modified asphalt mix has higher Marshall stability than the control mixtures. It may be concluded that the modified asphalt mixture would be less susceptible to plastic deformation as characterized by Marshall Stability, this agrees with (Al-Bana’a, 2010) findings.

Fig. 8 shows the effect of short and long term aging periods on Marshall Flow. It can be observed that aging reduces the Marshall Flow values, this agrees with (Al-Jumaily 2007) findings. These reductions may be related to the stiffer mix obtained, and the reduction in fluidity of the binder. The addition of 8% crumb rubber reduces the Marshall flow as compared with virgin mixture. After increasing the rubber to 16%, the flow values increase as compared with 8% rubber; this may be due to the decrease in adhesion between the components of the mixture, reflecting that rubber percentage is in excess. All the modified mixes exhibit low flow value when compared with that of virgin mix. Mixture with 16% crumb rubber give lower flow than virgin mixture after the aging process, but has more flow than 8% rubber. This indicates that 8% rubber gives less permanent deformation than other mixture.

The effect of short and long-term aging on the bulk Density is illustrated in Fig.9. This figure indicates that aging process decreases the bulk density of the mixtures. After adding rubber to mixture, the bulk density of the control mixture is higher than that of the modified asphalt concrete mixtures. The bulk density decreases with increase in crumb rubber content, this may be related to that the rubber exhibit resistance to compaction by the addition of more flexibility to mixture, such result agrees with (Al-Bana’a 2010) and (Sarsam and Lafta, 2014) findings. Air void in the mixture is an important parameter because percentage of air voids is related to durability of asphalt mixture. Fig. 10 shows the effect of short and long-term aging times on percent voids in total mix (VTM). It is clear that the air void increases with increasing aging time; modified asphalt gives high air void as compared to virgin mixture. When the percentage of rubber is increased, the air void increases, this agrees with (Al-Bana’a 2010) and (Sarsam, 2007) finding. It was found that 8 hr. aging shows more air void than 2 day long-term aging but less than that of 5 day aging. This could be related to the fact that when loose mixture is subjected to aging, it becomes difficult to compact as it becomes very hard.
Fig. 9: Impact of crumb rubber and aging on bulk density

Fig. 10: Impact of crumb rubber and aging on total voids

Fig. 11: Impact of crumb rubber and aging on VFA

4.4. Effect of rubber and Aging on Indirect Tensile Strength Test

The indirect tensile (ITS) strength test is related to the cracking properties of the pavement. In order to evaluate the mixture resistance to variation in temperatures, different testing temperatures are used (25, 40 °C). The (ITS) at 25 °C has been tested for virgin and modified asphalt concrete. Fig. 12 shows part of the prepared specimens for ITS test. The effect of aging times on (ITS) at 25 °C is illustrated in fig.13. Results indicate that (ITS) at control-virgin, condition is 1307 KPa. After 8hr aging, the (ITS) increased to 29.7% as compared with the control mix value. At 5 day aging the (ITS) increased to 54.85%. When adding rubber by 8%, the ITS value was increased by 19.9% as compared with control modified mix. When the mixture was subjected to 8 hr. aging, the ITS value exceeds the control modified mixture by 32%. After 5 days, aging the increment was 56.25% as compared with control- modified mix. When the rubber content was duplicated the (ITS) has the same trend of 8%.
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The value of ITS when tested at 40 °C for control virgin condition as shown in fig 14 was 557 KPa. After 8 hr. aging, the (ITS) increased to 48.4% as compared with the control mix value. At 5 day aging the (ITS) increased to 54.7%. When the mixture experiences 8 hr. aging, the (ITS) value rises by 31.8% more than the control modified mixture value. After 5 day long aging the increment was 67.2% as compared with control-modified mix.

When the rubber content was duplicated, the (ITS) increased by 42.5% and 9.5% as compared with virgin mix and mix with 8% rubber content by respectively. After 8 hr. aging, mix with 16% rubber shows higher (ITS) than that of 8% by (12.7%). The 5 day aging still shows higher (ITS) than control modified mixture.

4.5. Effect of rubber and Aging on Resilient Modulus Test

Resilient modulus Mr represents the ratio of an applied stress to the recoverable strain that takes place after the applied stress has been removed. The aging processing seems to provide more stiffness, which possibly indicates a greater resistance to permanent deformation. This leads to higher resilient modulus. Resilient modulus of the modified mixes is significantly higher than the values obtained for control mixture. Table 7 shows that the resilient modulus increases with the increasing of aging period. This may be related to increase in stiffness. Such result is compatible with (Sarsam and Al-Sadik, 2014) and (Sarsam and AL-Zubaidi, 2014) findings. When crumb rubber is added to the mixture, the Mr value was higher than that of virgin mixture .This is related to the fact that rubber content gives more stiffness to mixture. After the aging process, the Mr of modified mixture continues to increase with aging period. Higher resilient modulus results will generate great rutting resistance development in the asphalt pavements as cited by (Abdelaziz and Karim, 2003).

4.6. Effect of rubber and Aging on Resistance to Permanent Deformation

Permanent Deformation was measured using the dynamic indirect tensile test; the pneumatic repeated load system shown in fig 15 was implemented. The permanent vertical plastic strain is measured at temperature of 40 °C and a stress level of 0.138 MPa. The intercept (a) represents the permanent strain at N=1, where N is the number of the load cycles. The higher value of intercept, the larger strain and hence the larger the potential for permanent deformation as mentioned in the study carried out by (Dreessen et al, 2010). While slope (b) represents the rate of change in the permanent strain as a function of the change in loading cycles (N) in the log-log scale, high slope values for a mix indicate an increase in the material deformation rate hence less resistance against rutting. A mix with a low slope value is preferable as it prevents the occurrence of the rutting distress mechanism at a slower rate. The results of permanent deformation tests are shown in fig 16. on the other hand, the effect of crumb rubber on permanent microstrain is presented in fig.17. The analysis of permanent deformation in this study is based on intercept, slope parameters and permanent deformation at 1,000 load cycles. The values of permanent deformation (microstrain) for each asphalt mixture are presented in Table 7. The 8 hr. short term aging process decreases the permanent deformation by 35.2% for asphalt cement mix as compared with control mix. When aging the mixture for 5 day the permanent deformation decreased by 59.3% for asphalt cement as compared with control mix. Such results indicate that the aging process makes the mixture stiffer, which leads to reduction in the pavement deformation. When 8% crumb rubber was added, the permanent deformation decreased by 21 % with respect to control mix. This means that the modified asphalt concrete has lower permanent deformation when compared to control mixture.
### Table 7: Impact of crumb rubber and aging time on physical properties of asphalt concrete

<table>
<thead>
<tr>
<th>Rubber content %</th>
<th>Aging time</th>
<th>Permanent microstrain @ 1000 load cycles</th>
<th>$\varepsilon = a N^b$</th>
<th>Resilient modulus (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Intercept (a)</td>
<td>Slope (b)</td>
</tr>
<tr>
<td>Control</td>
<td>0 – hours</td>
<td>6545</td>
<td>261.57</td>
<td>0.466</td>
</tr>
<tr>
<td>0% Rubber</td>
<td>4 - hours</td>
<td>5615</td>
<td>240.6</td>
<td>0.456</td>
</tr>
<tr>
<td></td>
<td>8 - hours</td>
<td>4243</td>
<td>208.7</td>
<td>0.436</td>
</tr>
<tr>
<td></td>
<td>2 - days</td>
<td>3357</td>
<td>174.7</td>
<td>0.427</td>
</tr>
<tr>
<td></td>
<td>5 - days</td>
<td>2666</td>
<td>156.0</td>
<td>0.410</td>
</tr>
<tr>
<td>8% Rubber</td>
<td>0 - hours</td>
<td>5170</td>
<td>239.8</td>
<td>0.444</td>
</tr>
<tr>
<td></td>
<td>4 - hours</td>
<td>4405</td>
<td>206.6</td>
<td>0.442</td>
</tr>
<tr>
<td></td>
<td>8 - hours</td>
<td>3079</td>
<td>178.9</td>
<td>0.411</td>
</tr>
<tr>
<td></td>
<td>2 - days</td>
<td>2566</td>
<td>160.0</td>
<td>0.401</td>
</tr>
<tr>
<td></td>
<td>5 - days</td>
<td>1970</td>
<td>128.3</td>
<td>0.395</td>
</tr>
<tr>
<td>16% Rubber</td>
<td>0 - hours</td>
<td>5402</td>
<td>244.3</td>
<td>0.448</td>
</tr>
<tr>
<td></td>
<td>4 - hours</td>
<td>4696</td>
<td>215.8</td>
<td>0.445</td>
</tr>
<tr>
<td></td>
<td>8 - hours</td>
<td>3306</td>
<td>177.3</td>
<td>0.423</td>
</tr>
<tr>
<td></td>
<td>2 - days</td>
<td>2894</td>
<td>164.0</td>
<td>0.415</td>
</tr>
<tr>
<td></td>
<td>5 - days</td>
<td>2537</td>
<td>149.3</td>
<td>0.410</td>
</tr>
</tbody>
</table>

When aging the modified mixture to 8 hr., the permanent deformation was decreased by 40.4% as compared with control-modified mix. After the mixture was subjected to 5 day of long-term aging, the permanent deformation decreased by 61.9 % as compared with control-modified mix. When duplicating the rubber content, the mixture shows lower deformation than that of control mixes. On the other hand, it shows higher deformation than that when 8% rubber was introduced. This behavior is also indicating that 16% rubber is an excess amount, and 8% rubber is sufficient for modification of asphalt concrete from permanent deformation point of view.

The intercept values shown in table 7 decreases as the aging time increases, this means that the aging exhibit lower microstrain at initial load cycles .When rubber is added the intercept value decreases as compared with control mix, this indicates that modified asphalt reduces the potential of permanent deformation.

The slope values are shown in Table 7. The control-mix slope value is higher than that of mix with 8 hr. aging by 7.3% and higher than 5 day aging by 11.1%. When crumb rubber was added by 8%, the slope value was decreased by 4.6% for asphalt with respect to control mixture. After 8 hr. aging, the slope value was lower than that of modified mixture by 7.3%, and 5 days long term aging lower slope value by 11% as compared with the control modified mixture .This indicates that the aging process decreases the slope for modified and control mix. The same trends was shown after duplicating the rubber content but have slope value higher than that of the mix with 8% rubber and lower than virgin mix. It was noted that the difference in the slope between 8 hr. and 2 days aging periods is not significant. Addition of 8% crumb rubber to asphalt cement has change the physical and rheological properties of asphalt cement; it effectively decreases the penetration, ductility and creep stiffness values. It also improves mixture properties by increasing Marshall Stability, indirect tensile strength at 25 and 40° C, and resilient modulus. The addition of rubber is able to overcome the negative impact of short and long-term aging on asphalt cement and asphalt concrete.

![Fig. 15: Pneumatic repeated load system](image1)

![Fig. 16: Effect of aging on permanent deformation for virgin mix](image2)
5. CONCLUSIONS

1- Short-term aging for 7 hours of asphalt cement make the asphalt stiffer, that lead to decreased penetration by (47.2%), ductility (49.6%) and increased softening point (10.7%) and creep stiffness (79.2%).

2- Aging of asphalt concrete increases Marshall Stability by (49.6% and 66%), VTM (26% and 37.5%), indirect tensile strength at 25 °C (31.5% and 51.6%), indirect tensile strength at 40 °C (42.1% and 74.8%) and the resilient modulus (7.6% and 18.6%) for short and long-term aging respectively.

3- The resistance of aged mixtures against permanent deformation decreased by (60%, 56.25%, 67.2% and 21.8%) at 25 °C when compared to control modified mixture. Transportation Research Record No. 1810, Transportation Research Board, paper No. 02-2127).

4- Addition of 8% crumb rubber to asphalt cement has change the physical and rheological properties of asphalt cement, it effectively decreases the penetration, ductility and creep stiffness values by (21.6%, 62.9%, 15.6%), and leads to increased softening point by (4.7%).

5- The addition of (8%) crumb rubber improves mixture properties by increasing Marshall stability, indirect tensile strength at 25 and 40° C, resilient modulus by(24.35 % ,19.9% , 30.34%, and 8.42 %) respectively as compared with control virgin mixture.

6- The permanent deformation under repeated load test exhibits low plastic deformation for modified mixture with 8% rubber by 21% when compared to control asphalt mixtures, while Aging modified asphalt mixture to 8 hr. reduces the permanent deformation decreased by 40.4% as compared with control modified mixture.

7- The 5 day long term aging of modified mixtures causes, the Marshall Stability, indirect tensile strength at 25 and 40 °C and resilient modulus to be increased by (60%, 56.25%, 67.2% and 21.8%) respectively as compared with control-modified mixture. The permanent deformation decreased by 61.9%, as compared with control modified mixture. 8% crumb rubber is able to overcome the negative impact of short and long term aging on asphalt cement and asphalt concrete.

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Contribution of Crumb Rubber in the Aging Process of Asphalt Concrete

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