ASPHALT RUBBER AGING PROPERTIES COMPARED TO NEAT ASPHALT

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ABSTRACT: The Arizona Department of Transportation has successfully used asphalt rubber binders for several decades to reduce cracking. Over a period of several decades from the 1970’s to the 1990’s many research studies and papers have documented the aging characteristics of asphalt rubber and neat asphalt(bitumen) in terms of penetration and viscosity testing. Data and findings from these studies are used to develop asphalt rubber and neat asphalt aging properties. The aging properties are described in terms of routine penetration and viscosity type asphalt aging comparisons. In addition PG grading G* and phase angle data are also represented over a four year period in the late 1990’s. The PG grading G* and phase angle are examined and related in a novel way to the routine asphalt test. The objective of this paper is to use this rather large body of accumulated asphalt test data to describe the rate of asphalt rubber and neat asphalt aging. In addition an effort is made to relate (model) older routine asphalt grading tests such as penetration and viscosity to newer PG asphalt grading tests such as G* and phase angle with respect to asphalt aging. Such relationships are deemed to be helpful in examining asphalt aging data and pavement performance data so that they may be used in various parts of the world that as of yet have not adopted the PG grading system.

KEY WORDS: Asphalt rubber, rubber, aging

1. BACKGROUND

The Arizona Department of Transportation (ADOT) conducted numerous research and special studies of asphalt rubber and neat asphalt (bitumen) over a 30 year period [1-16]. Although these various studies were directed at a myriad of topics many of them contained original asphalt rubber binder and neat asphalt (bitumen) properties and later aged properties derived from asphalt extracted from cores. The studies included pavements that ranged in age from new construction asphalt properties to extracting asphalt from 20 year old pavements. The intent of this paper is to show how the testing properties of the asphalt rubber and neat asphalt changed with aging in the field. The asphalt tests include the traditional tests; the penetration at 25°C, the micro-viscosity at 25°C, absolute viscosity at 60°C, kinematic viscosity at 135°C. The penetration, absolute viscosity and kinematic viscosity tests were specified and tested in accordance with AASHTO requirements which are similar to ASTM testing requirements. Besides traditional testing the binders, other testing to derive the G* and phase angle were conducted in accordance with the PG grading protocol [17]. Results of the core binder G* and phase angle tests were compared to a data base of the G* and phase angle for new asphalts tested in the late 1990’s. This G* and phase angle data base contains the original unaged, Rolling Thin Film Oven (RTFO) and Pressure Aging Vessel (PAV), G* and phase angle for hundreds of asphalts.

2. ARIZONA HISTORY OF ASPHALT AND ASPHALT RUBBER

Arizona used a variety of neat asphalts from 1966 to 2000. Over this long period of time the asphalt grades that were used or tried included 200/300, 120/150 or 85/100, 60/70 and 40/50 penetration [17]; AR2000 and AR4000; AC 30 and AC 40 [17]; PBA 3, PBA 4, PBA 6, PBA 7 [18], [19] and since 1997 the PG grades such as PG 70-10 [20]. These various grades of asphalt were used in dense graded mixes that were either designed using the Hveem or Marshall of mix design. Typically the average asphalt binder content was 5.4 percent by weight of the mix. The design air void content was 5 percent and the average VMA was 17 percent. Neat asphalt was also used in open graded mixes. The open graded mix has an average binder content of 6.0 percent by weight of the mix. The air void content typically was 20.8 percent and the average VMA was 29.1 percent.
Asphalt rubber binder is a mixture of 80 percent hot paving grade asphalt (bitumen) with 20 percent ground tire rubber produced from waste tires. Asphalt rubber binder is used in either a gap graded mix or open graded mix (Sousa, 2006). The asphalt rubber gap graded mix has an average binder content of 7.3 percent by weight of the mix. The design air void content was 5 percent and the average VMA was 20 percent. The asphalt rubber open graded mix has an average binder content of 9.2 percent by weight of the mix. The air void content typically was 20.2 percent and the average VMA was 32.5 percent. Figure 1 is a comparison of the average Hveem and Marshall dense graded mixes gradation to the average asphalt rubber gap graded mixes gradation. Figure 2 is a comparison of the gradation of the open graded mixes with neat asphalt to the asphalt rubber open graded mixes.

![Figure 1. Neat asphalt Hveem and Marshall gradation compared to the asphalt rubber gap graded mix design](image1.png)

![Figure 2. Gradation of open graded mixes with neat asphalt and asphalt rubber](image2.png)

**2. DESCRIPTION OF ASPHALT TESTS**

The asphalt tests in the data base include the penetration 25°C [22], the micro-viscosity at 25°C [23], [24], absolute viscosity at 60°C [25], kinematic viscosity at 135°C [26]. The penetration, absolute viscosity and kinematic viscosity tests were specified and tested in accordance with AASHTO requirements which are similar to ASTM testing requirements. The micro-viscometer tests were conducted in a manner consistent with published research literature and equipment manufacturer suggested test procedures. Micro-viscosities of unaged and aged asphalt were measured on a Hallikainen sliding plate micro-viscometer at a constant temperature of 25°C. Glass plates were used with unaged asphalt except for those viscosities above 5 MPa.s. For unaged
asphalts with viscosities above 5 MPa·s and for all aged asphalts from cores steel plates were used. For all asphalt samples that were tested successively lighter weights, which imposed smaller shear rates. Usually four shear rates were imposed on a sample. Based on the shear rates and shear stresses, the micro-viscosity was determined for a shear rate of 0.05 sec⁻¹, [27].

Asphalt tests were conducted on the asphalt binder sample from the tank at the time of construction, referred to as the original unaged asphalt. None of the asphalts in the data base were specified to be modified and virtually all are unmodified, neat asphalts, albeit some modification may have been done but not reported. Later as required by the various research studies cores of the pavement were taken and the asphalt extracted by means of an ADOT extraction test [28]. In all 157 different test sites were cored and asphalt recovered. The tested asphalt varied in age from 1 month to 264 months in age.

4. PENETRATION AND VISCOITY DATA ANALYSIS

The penetration and viscosity data was analyzed to estimate the rate of aging. Equations for the aging of the neat asphalt were derived for penetration and viscosity. Table 1 shows the derived equations. Table 2 covert the values from the equations to index values at one, five, ten and twenty years. By multiplying the tabled index values by the original penetration and viscosity values can be estimated over a period of years. Table 2 demonstrates the viscosity at 25°C increases more rapidly than the 60°C, and the 60°C viscosity increases more rapidly than the 135°C.

Table 1. Equations derived from asphalt recovered from field cores

<table>
<thead>
<tr>
<th>Asphalt Test</th>
<th>Original Value Unaged</th>
<th>Equation – Age in Months</th>
<th>Number of Observations</th>
<th>Correlation R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penetration 25C</td>
<td>100</td>
<td>-10.6*LN(Age)+62.42</td>
<td>157</td>
<td>0.403</td>
</tr>
<tr>
<td>Micro-Viscosity 25C, 10⁶ Pa·s</td>
<td>0.150</td>
<td>0.50047*e⁻⁰.⁰¹⁹Age</td>
<td>157</td>
<td>0.559</td>
</tr>
<tr>
<td>Absolute Viscosity 60C, Pa·s</td>
<td>170.0</td>
<td>619.6*e⁻⁰.⁰⁴²⁷Age</td>
<td>157</td>
<td>0.438</td>
</tr>
<tr>
<td>Kinematic Viscosity 135C, Pa·s</td>
<td>0.310</td>
<td>45.44*e⁻⁰.⁰⁰⁴⁷Age</td>
<td>157</td>
<td>0.408</td>
</tr>
</tbody>
</table>

Table 2. Index values derived from equations in Table 1

<table>
<thead>
<tr>
<th>Age in Months</th>
<th>Penetration Index 25°C</th>
<th>Micro-Viscosity Index 25°C</th>
<th>Absolute Viscosity Index 60°C</th>
<th>Kinematic Viscosity Index 135°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>0.62</td>
<td>4.3</td>
<td>4.3</td>
<td>1.6</td>
</tr>
<tr>
<td>60</td>
<td>0.45</td>
<td>10.7</td>
<td>8.4</td>
<td>1.9</td>
</tr>
<tr>
<td>120</td>
<td>0.37</td>
<td>33.5</td>
<td>19.8</td>
<td>2.6</td>
</tr>
<tr>
<td>180</td>
<td>0.33</td>
<td>104.8</td>
<td>46.4</td>
<td>3.5</td>
</tr>
<tr>
<td>240</td>
<td>0.29</td>
<td>327.6</td>
<td>108.7</td>
<td>4.5</td>
</tr>
</tbody>
</table>

5. DATA ANALYSIS NEAT ASPHALT

Besides reviewing the penetration and viscosity versus time in months, i.e., aging another portion of this study is to attempt to relate the Penetration to the micro-viscosity at 25°C. Then relate the micro-viscosity to the PG grading PAV Phase angle since the phase angle represents the viscous portion of the mechanical analysis. If all of these relationships could be reasonably derived then the following scheme could be used to estimate the PG grading PAV G* and Phase angle from the 25 C penetration and related micro-viscosity as diagrammatically shown as follows:

Penetration → Microviscosity → Phase Angle(δ) → G*
As a first step the 25°C penetration of the asphalt was correlated to the 25°C micro-viscosity. The correlation equation is shown as follows and Table 3 shows the micro-viscosity predicted from the penetration:

Micro-viscosity (MPa·s) = 354.4*(Penetration)$^{1.848}$  \( (1) \)

\[ R^2 = 0.8121 \quad N = 157 \]

Table 3. Micro-viscosity predicted from penetration; Phase angle predicted from Micro-viscosity; G* predicted from Phase Angle

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>354</td>
<td>12</td>
<td>1200000</td>
<td>60</td>
<td>0.18</td>
<td>58</td>
<td>290</td>
</tr>
<tr>
<td>2</td>
<td>99</td>
<td>19</td>
<td>340000</td>
<td>80</td>
<td>0.11</td>
<td>60</td>
<td>200</td>
</tr>
<tr>
<td>5</td>
<td>18</td>
<td>30</td>
<td>460000</td>
<td>100</td>
<td>0.07</td>
<td>63</td>
<td>116</td>
</tr>
<tr>
<td>10</td>
<td>5.0</td>
<td>37</td>
<td>130000</td>
<td>120</td>
<td>0.05</td>
<td>65</td>
<td>81</td>
</tr>
<tr>
<td>20</td>
<td>1.4</td>
<td>45</td>
<td>30000</td>
<td>150</td>
<td>0.03</td>
<td>69</td>
<td>39</td>
</tr>
<tr>
<td>40</td>
<td>0.39</td>
<td>53</td>
<td>7100</td>
<td>200</td>
<td>0.02</td>
<td>71</td>
<td>27</td>
</tr>
<tr>
<td>50</td>
<td>0.26</td>
<td>55</td>
<td>4900</td>
<td>250</td>
<td>0.013</td>
<td>74</td>
<td>16</td>
</tr>
</tbody>
</table>

In the next step the micro-viscosity at 25°C was related to phase angle at 25°C from tests conducted on the neat asphalt recovered from the cores and additional unaged asphalts. The resultant equation was found and predicted values are shown in Table 3:

Phase angle (δ) = -6.059*Ln(micro-viscosity)+61.25 \( (2) \)

\[ R^2 = 0.8530 \quad N = 157 \]

Next step was to predict the G* from the phase angle using the original, rolling thin film oven (RTFO) and pressure aging vessel (PAV) values obtained by routine testing in the late 1990’s and more recently 2010 [29]. The following equation was derived from the correlation, representative of a Blacks diagram predicted values are shown in Table 3:

Phase angle (δ) = -5.5172*Ln(G*)+89.2146 \( (3) \)

\[ R^2 = 0.9822 \quad N = 957 \]

Equation (3) is re-written to directly solve for G* as shown in Equation (4) as follows:

\[ G* = e^{\frac{\delta - 89.2146}{-5.5172}} \] \( (4) \)

With the prediction of G* from the phase angle it was possible to calculate a predicted G*Sinδ and match these values to the percent observed cracking in the field. The ADOT estimates the percent cracking visually as part of an annual pavement management review of the Arizona state highways using a cracking picture guide, Figure 3.
Figure 3. ADOT Standard Percent Cracking Photos, Percent by Area of High Traffic Lane Cracked (Way, 1979)

Reviewing the estimated $G\cdot \sin\delta$ in terms of the degree of cracking provided the following equation:

$$\text{Percent Cracking} = -14.078 + 2.492 \cdot \ln(G \cdot \sin\delta)$$  \hspace{1cm} (4)

$$R^2 = 0.3904 \hspace{1cm} N = 157$$

In addition an equation was developed that related $G \cdot \sin\delta$ to the number of months of aging of the asphalt in the field.

$$\ln(G \cdot \sin\delta) = 6.822 + 0.0192 \cdot (\text{Age in Months})$$  \hspace{1cm} (5)

$$R^2 = 0.6774 \hspace{1cm} N = 157$$

It is interesting that the $G \cdot \sin\delta$ is better related to the age of the asphalt than to the percent cracking, albeit the level of percent cracking is very subjective in nature. In addition to predictive equations another way of representing the predicted $G \cdot \sin\delta$ is to review how the actual percent cracking and aging compared to $G \cdot \sin\delta$. Table 4 shows the $G \cdot \sin\delta$ cracking values below and above the 5000 kPa level and $G \cdot \sin\delta$ and average percent cracking at the end of five year periods. The 5000 kPa $G \cdot \sin\delta$ value obtained after RTFO and PAV aging. The pressure aging vessel (PAV) was adopted by Superpave to simulate the effects of long-term asphalt binder aging that occurs as a result of 5 to 10 years HMA pavement service [30-32]. On average from the Arizona data set the five to ten years of aging seems reasonable. Likewise the 5000 kPa $G \cdot \sin\delta$ value also is represented to equate to about ten percent cracking. The Arizona data, albeit limited, would indicate that the 5000 kPa value does not quite represent the ten percent level but is close and could easily represent a range of five to ten percent cracking. Although predicting cracking from $G \cdot \sin\delta$ is somewhat limited in certainty, it is clear, however that as the $G \cdot \sin\delta$ value increases the percent cracking increases.

Table 4. $G \cdot \sin\delta$ values in terms of predicting cracking and asphalt aging

<table>
<thead>
<tr>
<th>$G \cdot \sin\delta$ level</th>
<th>Average percent cracking</th>
<th>Average age of pavement months</th>
<th>Age in Months</th>
<th>Average percent cracking</th>
<th>$G \cdot \sin\delta$ kPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>$G \cdot \sin\delta&lt;5000$ kPa</td>
<td>2.0</td>
<td>28</td>
<td>0-60</td>
<td>0.5</td>
<td>3150</td>
</tr>
<tr>
<td>$G \cdot \sin\delta&gt;5000$ kPa</td>
<td>10.3</td>
<td>111</td>
<td>61-120</td>
<td>7.7</td>
<td>31800</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>121-180</td>
<td>16.7</td>
<td>51100</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>180-264</td>
<td>22.2</td>
<td>178000</td>
</tr>
</tbody>
</table>
6. DATA ANALYSIS ASPHALT RUBBER

A very limited study was conducted to compare the aging of pavements constructed with asphalt rubber gap graded and open graded mixes. It is theorized that since these asphalt rubber mixes are placed with a great amount of asphalt and a thicker filmthickness the asphalt binder will age slower and there will be less cracking [33]. Figure 4 shows the results from cores taken from pavements with asphalt rubber and neat asphalt in the same age bracket of over 100 months in age show the asphalt rubber asphalt binder has a higher phase angle indicative of a greater portion of viscous material. Likewise the higher the phase angle the smaller the $G'$ elastic component, in essence the asphalt rubber is a less brittle material at the same age as the neat asphalt.

![Figure 4. Correlation of Laboratory Phase Angle – Age Relationship with Field Core-Aged Binder Test Results](image)

Historically it has been shown that less cracking occurs over time with asphalt rubber binder than neat asphalt [34]. To further the evidence that asphalt rubber mixes are less brittle and therefore less prone to cracking over time, Figure 5 shows the percent cracking versus months of field aging for pavements with neat asphalt and asphalt rubber. As can be seen the asphalt rubber has less cracking over the 264 months of service.
7. CONCLUSIONS

The purpose of this study was to add to the body of knowledge on the aging characteristics of neat asphalt binders and asphalt rubber using more than 20 years of binder test data.

Assemble unaged and aged asphalt rubber and neat asphalt test data that constitutes a wide range of penetration, viscosity, and PG-grades, original, RTFO, and PAV aging conditions; over 157 test sections and 318 variety of asphalt cements, and over 957 test data points.

A large amount of unaged and aged neat asphalt data and a smaller amount of asphalt rubber data has been assembled and reviewed to observe the amount of asphalt aging that takes place in the field over a 20 year period. This data base is of benefit to show the manner and degree to which asphalt aging and corresponding penetration and viscosity of the neat asphalt changed over time the degree of cracking increases.

A scheme was developed to estimate Phase Angle and G* from penetration and micro-viscosity data (Penetration → Microviscosity → Phase Angle → G*). From this analysis scheme reasonable equations and correlations were derived to describe the rate of aging for neat asphalt in terms of G* and phase angle.

Relationships of penetration and viscosity of PG grades at 25°C were developed for the phase angle as this represents the viscous component of binder characteristics.

The 5000 kPa G*Sinδ value obtained after RTFO and PAV aging is represented to equate to the degree of aging after five to ten years in the field. On average from the Arizona data set the five to ten years of aging seems reasonable.

The Arizona data, albeit limited, would indicate that the 5000 kPa value does not quite represent the ten percent level of cracking but is close and could easily represent a range of five to ten percent cracking. Although predicting cracking from G*Sinδ is somewhat limited in certainty, it is clear, however that as the G*Sinδ value increases the percent cracking increases.

Asphalt rubber asphalt binder has a higher phase angle indicative of a greater portion of viscous material. Likewise the higher the phase angle the smaller the G* elastic component, in essence the asphalt rubber is a less brittle material at the same age as the neat asphalt.

Evidence from this study demonstrated that asphalt rubber mixes are less brittle and therefore less prone to cracking over time.
REFERENCES: