Influence of Time and Temperature on Asphalt Binders Rheological Properties

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Abstract: One of the major problems associated with the asphalt binders is its sensitivity towards the temperature. In Pakistan, asphalt binders have been selected for asphalt pavements on the basis of penetration grade, determined at 25°C. Temperature and loading time sensitivity of asphalt binders were never investigated before its applications. The effect of temperature and time of loading of three commonly used asphalt binders in Pakistan was investigated and compared to ascertain best performing binders under these conditions. Two neat asphalt binders of 60-70 and 40-50 penetration grade and modified 60-70 pen. grade bitumen with 1.6% elvaloy were studied at six temperatures of 18, 24,30,36,42 and 48°C and in a frequency range of 0.01Hz to 100Hz using a dynamic shear rheometer. Master curves are constructed and the shift factor curves are plotted to determine the temperature susceptibility of binders. Asphalt binder with 60-70 penetration grade and modified showed higher temperature sensitivity in all frequency and temperature ranges. Polymer modification improves asphalt binder stiffness. At higher temperature the shear modulus reduces drastically.

Keywords: Asphalt, Rheology, Master Curve, shift factor, Rutting,
2. Objectives

This research study mainly focuses on investigating the influence of temperature and frequency of loading on binder’s stiffness and on the temperature sensitivity of binders. Also, to compare the time and temperature response of modified binders with its base bitumen and similar penetration grade bitumen.

3. Experimental Programme

Two neat bitumen with penetration grade 40-50 and 60-70 asphalt binders were studied in addition to polymer modified bitumen (PMB), which was PG64-22 in Superpave testing. These binders have commonly been used in Pakistan on most of the highways. Samples were collected from Attock Refinery Limited, Pakistan. Ductility results of neat asphalt binders were over 100cm. Polymer modified asphalt was prepared by using 60-70 penetration grade bitumen and 1.6% Elvaloy terpolymer. This combination was used on those highways in the past, which were facing rutting problem. The penetration, softening point and ductility of PMB (PG 64-22) recorded in the laboratory were 47, 58°C and 65mm respectively. Based on penetration test, PG 64-22 lies in 40-50 pen. grade.

Testing on 25 mm diameter test specimen of bitumen was carried out on DSR as per AASHTO T-315 test protocol. Six temperatures of 18, 24,30,36,42 and 48°C in frequency range of 0.01Hz to 100Hz were selected that best simulate with the local field conditions. Frequency sweep test was run on neat and modified asphalt binder at 12% strain. Specimens in replicates were tested under each condition and results were computed to obtain complex shear modulus and phase angle. The result data sheets contained storage and loss modulus, deflection angle and viscosity values. Phase angle and shear modulus were computed from deflection angle and storage modulus respectively.

4. Result and Discussion

4.1 Viscosity

Asphalt binder viscosity data obtained from DSR was plotted against temperature as shown in Figure, to ascertain the relative effects of temperatures on viscosity. For simplicity and trend developments, viscosity values were taken on logarithmic scale.

Figure 1. Effect of Temperature on Viscosity

Figure 1 shows similar trends of decrease in viscosity with an increase in the temperatures and the rate of decrease depends on types of asphalt binder. Polymer modified bitumen has the lowest viscosity values at all temperatures. One can estimate the probability in variation of complex shear modulus from the viscosity trends.

4.2 Black Diagram

Black diagram was then constructed to ascertain the influence of phase on shear modulus at different temperatures. Typical plot of 60-70 penetration grade bitumen have been shown in Fig. 2

Figure 2 shows a drastic reduction of (G*) with increase in the viscous component (δ) as the test temperature increases. One can observed that the slope of line become steeper after 60°C and hence the loss of binder stiffness, which may directly affect the asphalt mixtures rutting potential in the field.

4.3 Rut Factor

Rut factor (G*/sinδ) that indicates binder ability to resist rutting was also computed for each binder and compared graphically at a typical frequency of 0.1Hz as shown in Figure 3.
4.4 Master Curve Constructions

Master curves were then constructed on reference temperature of 30°C by providing horizontal shift of the data obtained from each temperature. Nonlinear least square regression technique was used for fitting the sigmoidal curve to the measured shear complex modulus test data. Other coefficients of sigmoidal functions (δ, α, β, & γ) were also determined simultaneously and reported in Table 1. This data would be useful for the practitioners for their research comparisons. The shear modulus master curve can be presented by the sigmoidal functions as described by MEPDG in the following equation (MEPDG, 2002).

\[
\log \left( \frac{E^*}{\sin \delta} \right) = \delta + \frac{\alpha}{1 + e^{\beta + \gamma \log T}}
\]

Where δ, α are known to be the fitting parameters that depend on aggregate gradation, binder contents and air void. The parameter δ is the lower asymptote that represents the minimum value of E*. δ +α is upper asymptote that represents the maximum value of E*. Parameters β, γ depend on characteristics of asphalt binder and describes the shape of the sigmoidal functions. Also (β/γ) ratio is known to be the inflection point/frequency. Above coefficients of sigmoidal functions (δ, α, β, & γ) were determined simultaneously and reported in Table 1. The purpose of providing these coefficients is to provide information to the researchers for their research comparisons.

Table 1. Sigmoidal parameters for binders

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Penetration Grade 40-50</th>
<th>Penetration Grade 60-70</th>
<th>PMB</th>
</tr>
</thead>
<tbody>
<tr>
<td>δ</td>
<td>0.78</td>
<td>0.76</td>
<td>0.809</td>
</tr>
<tr>
<td>α</td>
<td>-4.57</td>
<td>-50.26</td>
<td>-92.324</td>
</tr>
<tr>
<td>β</td>
<td>3.61</td>
<td>5.74</td>
<td>6.164</td>
</tr>
<tr>
<td>γ</td>
<td>0.68</td>
<td>0.71</td>
<td>0.280</td>
</tr>
</tbody>
</table>

A significant effect of temperature and frequency levels on asphalt cement flow and deformations characteristics have been noted, which is presented by constructing the master curves, computing horizontal shift factors and sigmoidal functions of the best fit curve. Master curves and shift factor describe the time and temperature dependency of material rheological behavior respectively. Shift factors were calculated to transfer the data from 18, 24, 42 and 48°C to 30°C. Shift factor helps in moving the curves plotted at different temperatures to a reference temperature. Results of shift factors for binders 40-50, 60-70 penetration grade and PMB were reported in Table 2.

Table 2. Horizontal Shift Factor

<table>
<thead>
<tr>
<th>Temp</th>
<th>Penetration Grade 60-70</th>
<th>Pen. Grade 40-50</th>
<th>PMB</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>1.75</td>
<td>1.88</td>
<td>2.05</td>
</tr>
<tr>
<td>24</td>
<td>0.87</td>
<td>1.02</td>
<td>1.21</td>
</tr>
<tr>
<td>30</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>36</td>
<td>-0.72</td>
<td>-0.57</td>
<td>-0.37</td>
</tr>
<tr>
<td>42</td>
<td>-1.45</td>
<td>-1.16</td>
<td>-0.89</td>
</tr>
<tr>
<td>48</td>
<td>-1.92</td>
<td>-1.69</td>
<td>-1.35</td>
</tr>
</tbody>
</table>

Table 2 shows reference temperature is 30°C and positive and negative sign indicate a shift of data from either side to 30°C. The amount of shift has been plotted in Figure 4 to study the most sensitive binder. Higher slope of shift factor plot shows more sensitive binder towards temperature.

Figure 4 describes graphical presentation of shift factors plotted against temperature. The slope of the curve indicates material sensitivity towards change in temperature. Figure 4 showed that 60-70 penetration grade is more sensitive to temperature and PMB as least sensitive asphalt binder.

The basic objective of construction of master curve was to characterize the binder over a wide range of temperature and loading frequencies. This
The degree of determinacy ($R^2$) in Figure 5-7 indicates a best curve fitting technique have been used for presentation of temperature over a wide range of frequency. Masters curves of binders were plotted on single space for relative comparison as shown in Figure 8. The main objective is to depict most sensitive binder.

5. Conclusion

In this experimental study, three binders were investigated under different temperature and frequency of loading. Master curves were constructed and shift factor were computed to measure the temperature susceptibility of binders. Following conclusions have been drawn:

- High temperature has significant effect on flow and deformation characteristics of binders where binders exhibit almost viscous limits. Polymer modified bitumen showed better stiffness in terms of Complex shear modulus at 0.1Hz and 48$^\circ$C, whereas 60-70 penetration grade bitumen exhibits more viscous behavior in terms of phase angle.
- Asphalt binder 60-70 penetration grade was found to have higher temperature sensitivity as compared with other binders. The slope of shift factor curve for PMB is minimum as compared with other binders.
- Black diagram shows drastic loss of binder’s stiffness beyond 60$^\circ$C.

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