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 grades showed higher temperature sensitivity in all frequency and temperature ranges. Polymer modification improves asphalt binder stiffness. At higher temperature the shear modulus reduces drastically.
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1. Introduction

In Pakistan, high volumes of traffic in combination with the environmental impacts mainly cause pre-mature failure of the flexible pavements. Asphalt cement is the common material used in the construction of these pavements, usually in the surface courses. Apart from pavement design, asphalt mixture design, quality of materials and construction methodology, one has to carefully look into the selection of binder for specific project. Asphalt becomes hard and brittle in the cold weather while softens and viscous in the hot weather. Pavements using hard binders have low rutting potential, but more prone to fatigue and low temperature cracking. On the other hand, pavements using soft binders have more rutting potential, but less prone to fatigue and low temperature cracking. The main requirements of the binder's performance are its stiffness at any temperature and recovery after the release of loading. Conventional tests do not fully characterize asphalt cement for variation of temperature and frequency of loading which overlook its true behaviour in the field.

Three fundamental types of material behaviour that are relevant to the understanding of road building materials are Elasticity, plasticity, and viscosity (Molenaar 2001). For viscous (Newtonian) fluids, when the load is applied, the material exhibits stress in proportion to the rate of strain but not to the amount of strain (Ferry, 1980; Bird et al., 1987). The study of deformation and flow of bitumen explaining the elastic and viscous behavior under a state of stress is called Rheology (Thomas, 2002, Barnes et al., 1989). The principle rheological parameters are complex shear modulus (G*), and phase angle (δ), which can be measured using Dynamic Shear Rheometer. Complex modulus interprets the mathematical relationship between the shear stress to the shear strain and phase angle illustrate the elastic-viscous properties of the asphalt binder (Huang et al, 2007).

Similarly, Rheological parameters have been investigated for asphalt mixtures performance by other researchers [Burger et al 2001; Novak et al 2005; Edward et al 2006; Wassiuddin et al 2007; Yang et al 2008; Jamaluddin et al 2011]. Fernandes et al 2008 proposed the use of oil shale from sedimentary rock as a compatibilizer agent for polymer-modified asphalt binder. Yunquan et al, 2010 studied the effect of solvent de-asphalting on dynamic shear modulus of hard grade binders and concluded that the mixture with the hard-grade asphalt at high temperature increased significantly. Improving binder grade means enhancing the modulus value of mixes. At the same time the bending resistant ability at low temperature and the antifatigue ability were slightly reduces as compared to butadiene styrene modified asphalt PG70-28. Zou et al, 2010 used dynamic shearing test to investigate the morphology of binders and highlighted the importance of morphological parameters.

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.

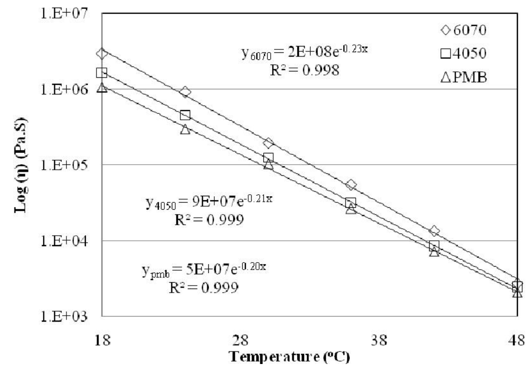

Figure 1. Effect of Temperature on Viscosity

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

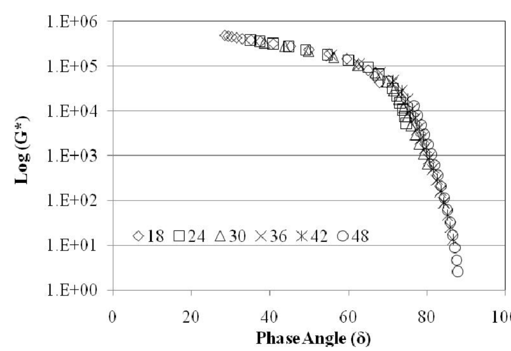

Figure2. Black Diagram of asphalt binders

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.

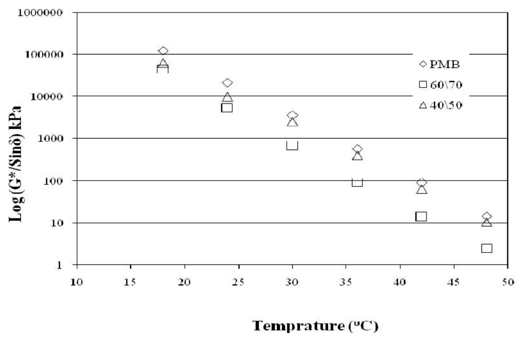

Figure3. Influence of Temperature on G*/Sin δ

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).

$$Log\left|E^{*}\right| = \delta + \frac{\alpha}{1 + e^{\beta + \gamma\left(\log T_{\gamma}\right)}} \quad (1)$$

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.

Table1. Sigmoidal parameters for binders

Parameters	Penetration Grade 40-50	Penetration Grade 60-70	PMB
δ	0.78	0.76	0.809
α	-4.57	-50.26	-92.324
β	3.61	5.74	6.164
γ	0.68	0.71	0.280

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

Table2. Horizontal Shift Factor

	Log Shift		
Temp	Penetration Grade 60-70	Pen. Grade 40-50	PMB
18	1.75	1.88	2.05
24	0.87	1.02	1.21
30	0	0	0
36	-0.72	-0.57	-0.37
42	-1.45	-1.16	-0.89
48	-1.92	-1.69	-1.35

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.

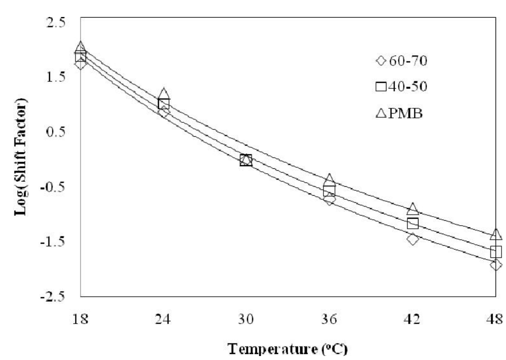

Figure4. Combine Shift factor curves

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 objective was achieved by conducting frequency sweep test on DSR. Single reference temperature is generally taken in a construction of master curve. Time and temperature superposition principle or principle of reduce variable that essentially describe the equivalency of time and temperature are the basis behind the construction of master curve. Master curve at reference temperature of 30°C has been constructed to complete the characterization of binders as shown in Figure 5-7, where values in terms of log of reduced time (Tr) are plotted against log G*.

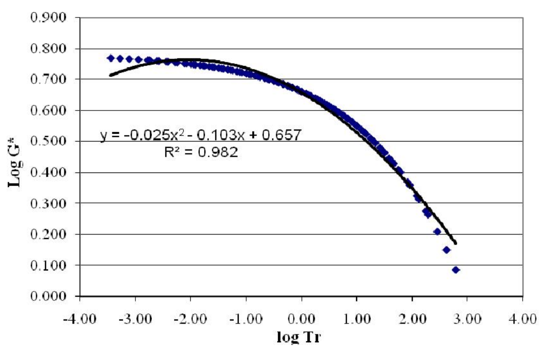

Figure5. Master Curve 40-50 penetration grade AC

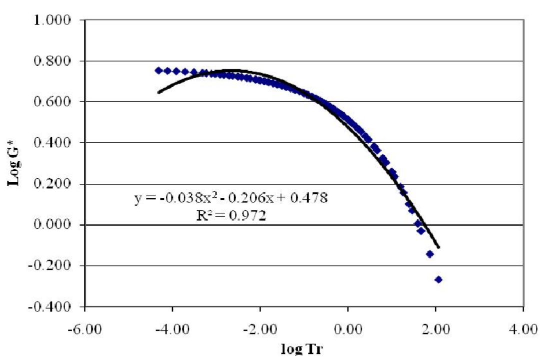

Figure 6. Master Curve 60-70 penetration grade AC

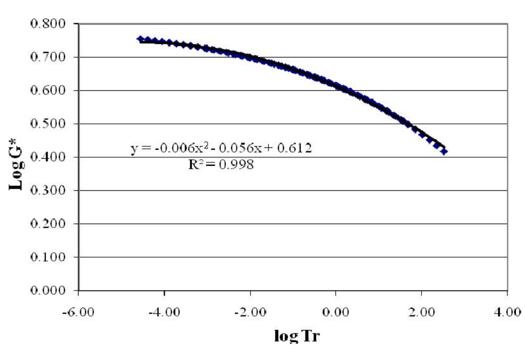

Figure 7. Master Curve of PMB

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**.**

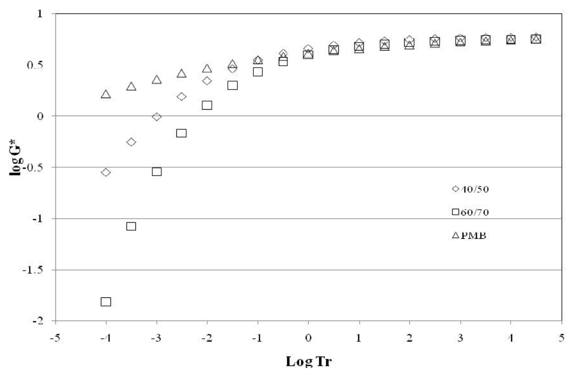

Figure 8. Combine Master Curve for Binders

Figure 8 showed that 60-70 is more temperature sensitive to time of loading than PMB and 40-50 penetration grade asphalt comes as intermediary bitumen. The slope of the curve indicates its sensitivity towards time of loading or frequency of loading. This also shows the application of binders in various regions. One can observe binders response over a frequency and temperature regime.

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°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°C.

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