To Study the viscoelastic behavior of Asphalt Binders using under Multi Stress Creep Recovery Test

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Abstract: Assessing the linear viscoelastic behavior of asphalt cement especially polymer modified binders using complex shear modulus (G*) alone has not been recommended by many researchers in the past. Assessing the rutting resistance of polymer modified binders in an oscillation test at low strain level does not really activate polymers to relate their performance in the field. Multi Stress Creep Recovery test applies higher levels of stress and strain to capture not only the stiffening effects of the polymer, but also the delayed elastic effects. The objective of this study was to assess the performance (load and temperature) in linear viscoelastic range of modified and neat asphalt binders commonly used in Pakistan. Seven different asphalt binders were tested for temperatures ranging from 20 to 70 degree centigrade and stress levels ranging from 0.025 to 25.6 kPa. The study revealed that the asphalt binders behave in a linear visco-elastic range up to 3.2 kPa. Non-recoverable creep compliance is the governing factor in the selection of an asphalt binder having sufficient elastic response at a particular stress level and temperature.
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1. Introduction

In Pakistan, conventional testing has been used to grade bitumen, which was developed on the basis of experience with unmodified binders. This procedure failed to characterize modified asphalt binders and their true performance in field. During the last few years Polymer Modified Binder (PMB) is used to cater for the improved traffic loading and for improved performance of the pavements. Polymer is supplied usually 2%-6% by weight, it enhances the characteristics of asphalt binders and offers safer pavements and minimizes the cost of the pavement [1]. Modified binders have higher elastic recovery and overall showed better resistance to fatigue cracking than unmodified binder [2]. The existing National Cooperative Highway Research Program (NCHRP) Project 9-10, protocols does not fully characterize all asphalt binders modified with different additives because they are based on simplifying assumptions that cannot be reliably extended to modified binders. Asphalt binder rut factor G*/Sinδ could not be used to fully characterize its high temperature elastic response [3].

This study covers identification of elastomeric response of asphalt binders by means of percent recovery obtained in the Multi Stress Creep Recovery (MSCR) test and a criterion which provides a mean for determining if the polymer used in modification will provide an elastomeric response or not. This test determines the mechanical properties of asphalt binders and creep compliance of asphalt cement and it can be used to predict rutting of asphalt mixes [4]. Performance of PMB depends upon stiffness of base binder, cross linking between base binder and polymers, and quantity and type of polymers used. The parameters of MSCR, non-recoverable creep compliance (J_{nr}), and percent recovery have been recently used to evaluate performance of binder and cross linking between base binders and polymers [5]. Since asphalt pavements are designed to be flexible, they must quickly return to their original configuration after loading. As creep is a time dependent function, it is important to monitor recovery per unit time or to stipulate time interval for an expected recovery. Non-recoverable creep compliance (kPa^{-1}) indicates the resistance of an asphalt binder to permanent deformation under repeated load. It can be defined as the residual strain in a specimen after a creep and recovery cycle divided by the stress applied as shown in the following relationship [6].

$$Jnr = avg.\frac{\gamma_u}{\tau} \tag{1}$$

Where 'γ_u' is the unrecovered strain from the end of the 9-sec recovery portion and 'τ' is shear stress applied during the 1-sec creep portion of the creep and recovery test. The non-recoverable creep compliance (J_{nr}) and the percent recovery (R%) are two of the parameters calculated from the measured strain under different stress cycles [7]. Previous research revealed that elastic component of visco-elastic behavior of asphalt cement can be improved either by improving the percentage of asphalt binder's basic constituents or by addition of modifiers.

Asphalt binders behave as linear visco-elastic material at low stress levels and vice versa. The threshold for the linear region depends on the composition of asphalt binder, loading time and temperature [8]. Within the linear range, the strain is proportional to stress at any instant, which is not true in the case of nonlinear range [9]. Specifically in the binder, the variations can be significant. Previous research reveals that the binder strains can vary between 1 and 500 times the mixture strain [10]. For these reasons, when the asphalt mixture is subjected to traffic loading, some of the binder performs in the visco-elastic range and some of the binders reaches the region of nonlinear behavior. Colbert et al (2012) characterized the rheological properties of asphalt binders blended with various amounts of asphalt extracted from a recycled asphalt pavement (RAP) mixture and concluded that there had been a significant differences in dynamic shear moduli master curve performance for high percentage RAP binder blends versus virgin binders at different aging states [11]. Similarly, highly crystalline bitumen, structured bitumen with high asphaltene content and highly modified bitumen can be well predicted using the existing models [12].

In the current study Multiple Stress Creep Recovery (MSCR) Test using a Dynamic Shear Rheometer (DSR) were carried out according to AASHTO TP70 specifications on seven neat and modified asphalt binders. The test consists of 10 cycles of creep and recovery each on eleven stress levels. Each cycle consists of one second of loading and 9 seconds of recovery upon instantaneous unloading.

2. Objectives

Following were the proposed objectives of the study;

i. To determine the non-recoverable compliance of the neat and modified asphalt binders and percentage recovery at different stress levels and temperature.
ii. To determine that if the polymer used in modification will provide an elastomeric response or not, and the effect of polymer on the rate of recovery
iii. To determine the maximum temperature for which the asphalt is workable under the Standard (S), Heavy (H) and Very heavy (V) type of traffic loading.

3. Experimental Programme

Five commonly used asphalt cements in high temperature and heavy loading pavements of Pakistan were selected for this study. Two asphalt cements were neat and five modified with different percentages of Elvaloy polymer. Penetration grading was also run to make a comparison with the PG grading. Table 1 shows the source from where the samples were collected and their respective penetration and performance grades. Rolling thin film oven short term aged asphalt specimens were subjected to MSCR test using the dynamic shear rheometer. Specimens were tested in replicates using a 25 mm disc and with 1mm gap setting for a temperature range of 20 to 70°C and stress ranges of 25 Pa to 25600 Pa. Percent recoverable and non-recoverable components of creep compliance were determined at the end of 10 cycles [6].

Table1. Designation of asphalt binders:

Performance Grade	Penetration Grade	Modified/ Unmodified
58-22	80-100	Unmodified
58-16	60-70	Unmodified
64-22	80-100	Modified with 2% Elvaloy
70-22	60-70	Modified with 1.35% Elvaloy
70-19	80-100	Modified with 1.7% Elvaloy
70-16	60-70	Modified with 1.7% Elvaloy
76-16	60-70	Modified with 2% Elvaloy

The tests were performed at the selected temperature using a constant stress creep of 1.0 second duration and a relaxation period of 9 second. The tests were performed at multiple stress levels of 0.025, 0.05, 0.1, 0.2, 0.4, 0.8, 1.6, 3.2, 6.4, 12.8 and 25.6 kPa at ten cycles for each stress level. Initial strain (ε_o) value at the beginning of creep portion of each cycle and strain value at the end of creep portion (ε_c) of each cycle were determined. The difference of both strains is known as adjusted strain (ε_1). Similarly, strain value (ε_r) at the, end of recovery portion of each cycle and adjusted strain value (ε_{10}) at the end of recovery portion of each cycle were computed using the following relationship;

$$\varepsilon_{10} = \varepsilon_r - \varepsilon_o \tag{2}$$

For each of the ten cycles the following at different creep stress levels were calculated. Percentage recovery for each cycle can be calculated by using the following relation;

$$Percentage\,Recovery = \frac{\varepsilon_{10} - \varepsilon_1}{\varepsilon_1} \times 100 \qquad (3)$$

The non-recoverable compliance was calculated at each stress level of each sample. Figure 1 shows the output of multiple stress creep recovery (MSCR) test and different variables that were found from this output.

Creep and strain measurements were recorded for different stress levels. From the recorded stress and strain values, Creep compliance (J_{nr}) and %age recovery were calculated. Creep compliance of asphalt binders were then compared at each stress level and temperature. Threshold stress levels of different asphalt binders for linear visco-elastic behavior were determined from the %age recovery. The amount of %age recovery may be an indication of the presence of an elastomeric polymer in the asphalt binder.

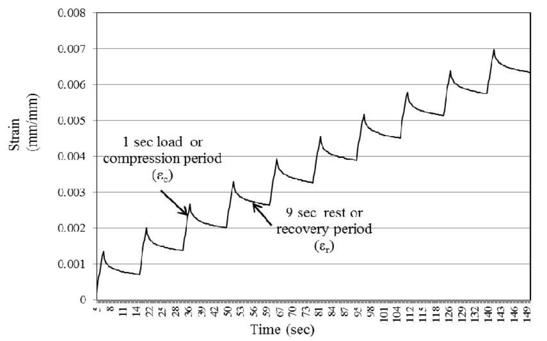

Figure 1. Typical 10 cycle's load and recovery in MSCR test

4. Results and Discussion

Influence of temperature and stress levels on creep compliance (J_{nr}) of asphalt binders were studied. Viscoelastic ranges for the asphalt binders were determined by comparing J_{nr} values with stress levels corresponding to each temperature.

4.1 Creep compliance (J_{nr}) of asphalt binders

Low (20°C), intermediate (40°C) and high (70°C) temperatures were selected for comparison of results. The values of J_{nr} for the seven asphalt sample at 20, 40 & 70 °C were plotted against a stress levels as shown in Figure 2, 3 and 4 respectively.

Figure 2-4 illustrate that stress levels has insignificant influence on Creep compliance at 20°C, while a significant effect at 70°C. This confirms that temperature has a significant influence on the non-recoverable creep behavior of asphalt binders. Also, higher PG grade has relatively low J_{nr} compared with low PG grade under all test conditions. High PG grade binders show more tendencies to recover upon release of stress than low grade binders. This tendency is a function of selected temperature and applied stress. Higher the J_{nr} value less will be the tendency of the asphalt binders to return back to its original shape and vice versa. Figures 3 and 4 also show almost constant slope of J_{nr} plot up to 3.2 kPa and after this stress level slope significantly so one can predict a linear visco-elastic behavior of asphalt binder up to 3.2 kPa stress level.

At 70°C, the J_{nr} value of PG 76-16 (with 2% Elvaloy) and PG 70-16 (with 1.7% Elvaloy) is lower than PG 70-122 (with 1.35% Elvaloy) asphalt binder. This shows that the creep compliance of modified asphalt binder is dependent upon the percentage of polymer added to asphalt specimen. Also rate of recovery with an increase in percentage Elvaloy from 1.35 to 1.7 at 40°C was higher than 70°C. The asphalt binder modified with 2% Elvaloy showed adequate elastic response even up to 70°C where as the binders modified with 1.7 and 1.35 % Elvaloy showed adequate elastic response up to 60°C respectively. High polymer contents asphalt binders has more rate of recovery than the low polymer content binders. In case of neat asphalt binders, PG 58-16 & 58-22 satisfied the elastic response criteria up to 50°C.

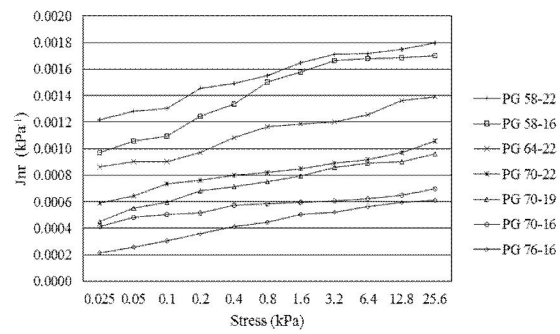

Figure 2. Influence of stress level on J_{nr} at 20°C

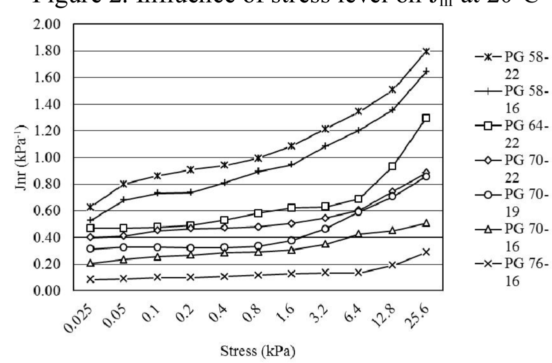

Figure 3. Influence of stress level on J_{nr} at 40°C

4.2 Elastic response of asphalt binders

Elastic responses of asphalt binders at different temperatures were depicted from J_{nr} values as per AASHTO TP70-10. Average percent recovery at 3.2 kPa was plotted against the average non recoverable creep compliance at same temperature. If the plotted point falls above the line on the graph, it shows that the asphalt binder was modified with an acceptable elastomeric polymer or in case of neat sample has sufficient elastic response at that temperature. Neat asphalt binder of PG 58-16 and PG 58-22 satisfied the elastic response criteria only up to 50^{o}C, whereas modified asphalt binders of PG 76 satisfied the elastic response criteria up to 70^{o}C. Figure 5 shows a typical relationship between J_{nr} and percentage recovery of PG 76-16 asphalt binder.

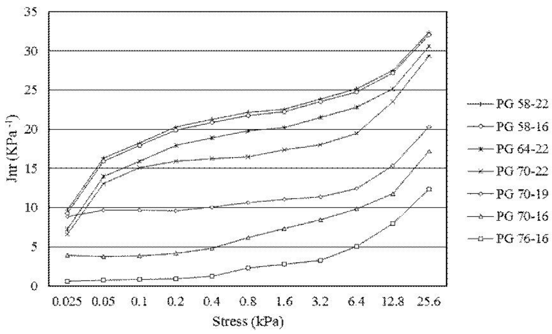

Figure 4. Influence of stress level on J_{nr} at 70^{o}C

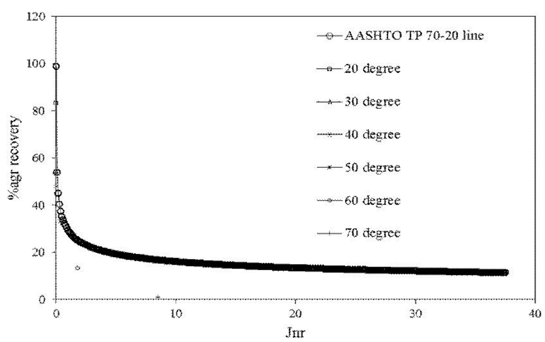

Figure5. Elastic response of PG 76-16 binder

The results for different asphalt samples were summarized in Table 2. This Table shows weather asphalt samples have been modified with sufficient polymer or in case of neat samples binder has sufficient elastic response at a particular temperature.

Table 2. Elastic response of asphalt binders

Sample Name	Modified with sufficient polymer/ in case of neat binder it has sufficient elastic response at stated temperature					
	20	30	40	50	60	70
PG 58-22	yes	yes	yes	Yes	No	no
PG 58-16	yes	yes	yes	yes	no	no
PG 64-22	yes	yes	yes	yes	yes	no
PG 70-22	yes	yes	yes	yes	yes	no
PG 70-19	yes	yes	yes	yes	yes	yes
PG 70-16	yes	yes	yes	yes	yes	yes
PG 76-16	yes	yes	yes	yes	yes	yes

It was observed that in case of modified asphalt binders, the binders modified with 2% Elvaloy showed adequate elastic response for a long range of temperature than the asphalt binders modified with 1.35% and 1.7% Elvaloy polymer. This percentage addition of polymer depends on the climatic temperature requirements at which the asphalt binder has to be used.

4.3 MSCR Binder Specification for grade bumping

Grade bumping of asphalt binders using AASHTO specifications for different types of traffic levels was carried out at the same pavement climate temperature of say 40^{o}C or 70^{o}C. For standard fast moving traffic J_{nr} requirement is 4.0 kPa-1and for slow moving or higher traffic the required J_{nr} value would be 2.0 or 1.0 to require a more rut resistant material. The J_{nr} values at 3.2 kPa shear stress using the MSCR test were calculated at different temperatures and used for evaluating the Standard (S), Heavy (H) and Very heavy (V) type of traffic under which the asphalt sample can be used at a particular temperature. For a specific temperature the J_{nr} value at 3.2 kPa less than 4, 2 and 1 were recommended for standard, heavy and very heavy traffic, respectively. The corresponding values of Equivalent Single Axle Loads (ESAL) for Standard (S), Heavy (H) and Very heavy (V) under traffic are less than 10 million, 10 to 30 million and greater than 30 million respectively. MSCR binder specifications for different performance grades have been shown in Table 3.

5. Conclusion

Following conclusions have been drawn from this study:

- Non-recoverable creep compliance (J_{nr}) differentiates asphalt binders of even same high temperature grade but having different percentage polymer.
- The asphalt binders behave in a linear visco-elastic range up to a stress level of 3.2 kPa.
- The addition of polymer in modified asphalt binders increases the stiffness of the binders and improves the viscoelastic properties.
- PG 76-16 only showed sufficiently elastic and modified for Very heavy traffic loading up 70^{o}C, whereas PG 58-22 is the least promising and highly stress-sensitive. It can only be used upto 40^{o}C for Very heavy traffic loading.

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Table 3. Grade bumping of asphalt binders using MSCR

Binder grade	Suitable traffic loading	Upper stress sensitivity limit	Suitable temperature limit for all type of loading
PG 58-22	V	70°C	Very heavy traffic loading = 40°C Heavy traffic loading = 50°C
PG 58-16	V	70°C	50°C
PG 64-22	V	60°C	Very heavy traffic loading = 50°C Heavy traffic loading = 60°C
PG 70-22	V	60°C	60°C
PG 70-19	V	50°C	50°C
PG 70-16	V	60°C	Very heavy traffic loading = 50°C Heavy traffic loading = 60°C
PG 76-16	V	50°C	50°C

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