Comparison of Neat and Modified Asphalt Binders Using Rheological Parameters under Virgin, RTFO and PAV Aged condition

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Abstract: True characterization of asphalt binders requires finding the rheological behavior at different temperature and stress levels. Asphalt binder's performance in the field mainly depends on its aging conditions that govern different rheological parameters. Five asphalt binders were tested in the laboratory at different aging conditions, using the dynamic shear Rheometer. The main objectives were to characterize the high temperature load response of asphalt binders under cyclic and static loading conditions. Two testing procedures have been adopted in the laboratory to investigate the high temperature stiffness and creep compliance of asphalt binders. Result shows that stiffness of asphalt binder increases and creep compliance decreases with aging. Creep compliance (J_{nr}) is temperature and stress sensitive parameter and behaves linear visco-elastic up to a stress level of 3.2 kPa. Temperature sensitivity depends upon the grade of asphalt binder.

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1. Introduction

Asphalt binders having penetration grade greater than 40 are usually used in construction of roads and less than grade 40 are used in industrial applications. Lower grades of bitumen are suitably used in hot climatic regions. Asphalt binder is used in pavements as a binder along with other materials and plays a vital role in pavement performance. Asphalt binder is a visco-elasto-plastic, time and temperature dependent material (Bahia et al, 2006). Selection of asphalt binder may be one of the significant causes behind pavement failure like rutting, cracking that reduce the serviceable life of pavements (Fernandes and Forte, 2008). Appropriate selection of binder depends upon its true characterization in the laboratory. Polymer modified binders (PMB) are becoming more popular because of their combine elastic and plastic properties, which are essential for long term pavement performance (Bahia et al, 2007). Unfortunately, these binders cannot be fully characterized using the conventional methods. Super pave testing procedures provides reliable results in a wide domain of temperature and stress levels (Rs and Bhia, 2009).Rheology provides basic information about the deformation and flow of asphalt binders. Normal tests which calculate essential properties are also used in obtaining rheological performance of asphalt binders, serves as the source for an effectual performance based asphalt binder specification (Colbert and Zhanping, 2012). Statistical analysis indicates that the asphalt binder's source and grade plays a key role in determining rheological properties (Kumar and Garg, 2011). Present study investigates the performance of different asphalt binders using frequency sweep and multi stress creep recovery tests. Asphalt binders were collected from Attock & National refineries, UAE & Uzbekistan. Asphalt binders from UAE and Uzbekistan were used in Afghanistan at Torkham Jalalabad road project, which has loadings and traffic conditions similar to Pakistan. Virgin, RTFO aged, PAV aged asphalt binders were tested in the laboratory using frequency sweep and creep recovery test.

2. Objectives

- To characterized the high temperature performance of neat and modified asphalt binder.
- To identify binder that are overly stress sensitive, which would previously have passed the PG criteria and potentially been susceptible to rutting in the field.
- To study of linear visco-elastic response of asphalt binders at various temperatures and stress levels.
- To characterization of asphalt samples according to the MSCR test specification.

3. Experimental Program

Frequency and temperature sweep testing was conducted on virgin, RTFO and PAV aged asphalt binders using dynamic shear rheometer (DSR). Asphalt binder specimen was heated at 90°C to pour into silicone mold. Five asphalt binders, four neat and one modified with Elvaloy polymer were tested. Specimens were tested using frequency ranges from 0.1Hz to 100Hz and temperature ranges from 10^{o}C to 70^{o}C with an interval of 10^{o}C and a strain rate of 12% (neat), 10% (RTFO aged) and 1% (PAV aged)was used (Masad et al, 2008). Test temperatures were selected based on the maximum and minimum pavement temperatures. Table 1 shows the penetration grade and performance grade of the asphalt samples.

Table 1. Designation of asphalt binders

Performance Grade	Penetration Grade	Modified/ Unmodified
58-22	80-100	Attock Refinery, Rawalpindi
64-25	60-70	National Refinery, Karachi
58-22	60-70	Uzbekistan Refinery
64-22	60-70	Unit Arab Emirates Refinery
70-22	60-70	Attock Refinery, Rawalpindi Modified with 1.7% Elvaloy

3.1 Frequency Sweep Test

Influence of frequency, temperature, PG grade, ageing on complex modulus, phase angle and viscosity were studied. Low (10^{o}C), intermediate (30^{o}C) and high (70^{o}C) temperatures were selected for comparison of results. The results are compared in Figure 1 at frequency of 0.1Hz as it is critical and identical to the loading conditions in Pakistan. All the temperature ranges are considered while comparing the results. PG 58-22 show the overall minimum value of G* at 70^{o}C at frequency of 0.1Hz, in neat type of asphalt binders for both the national and international asphalt binder.

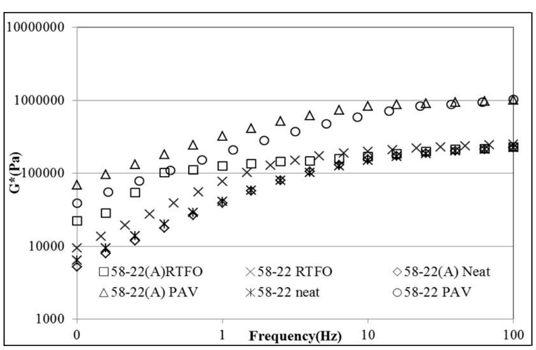

Figure 1. Influence of frequency sweep on G* at 30^{o}C for PG 58-22

Figure 1 reveals that PG 58-22 of Attock refinery has the overall maximum value of complex shear modulus at 10^{o}C in PAV aged type as compare to PG 58-22 of UAE refinery. PG 64-25 of Attock refinery shows the overall minimum value of complex shear modulus (same minimum value) in both the neat and RTFO aged type as compare to PG 64-22 of Uzbekistan refinery, at temperature of 70^{o}C and at the frequency of 0.1Hz. PG 64-25 shows the overall maximum value of complex shear modulus in PAV aged type of asphalt binder at a temperature of 10^{o}C. Figure 2 shows the comparison of PG 64-25 & PG 64-22 for G* at 30^{o}C.

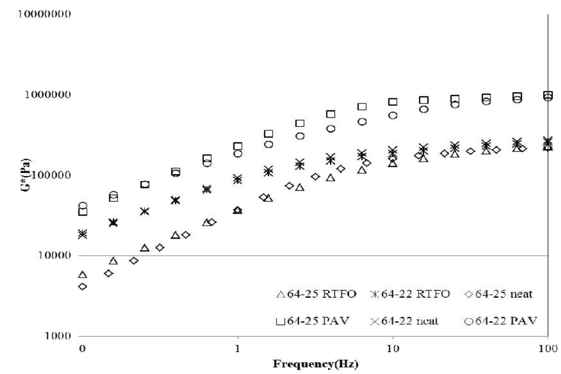

Figure 2. Influence of frequency sweep on G* at 30^{o}C for PG 64-25 & PG 64-22.The influence of frequency sweep on phase angle has been presented in Figure 3. PG 58-22 of UAE refinery show overall minimum values of phase angle compared to PG 58-22 of Attock refinery at frequency of 0.1Hz and temperature of 10^{o}C, similarly PG 58-22 of UAE shows the overall maximum value of phase angle in RTFO aged type of asphalt binder at 70^{o}C compare to PG 58-22 of Attock refinery.

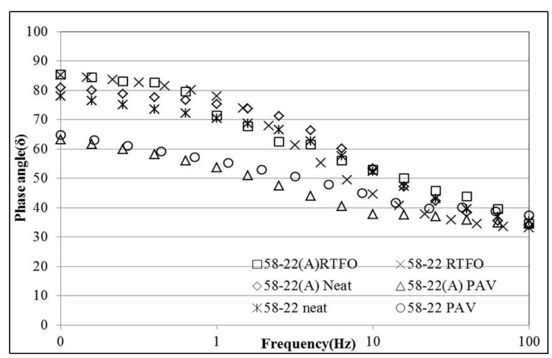

Figure 3. Influence of frequency sweep on phase angle at 30^{o}C for PG 58-22

Similarly, PG 64-22 of Uzbekistan refinery as presented in Figure 4 shows the minimum value of phase angle in RTFO aged asphalt binder at 10^{o}C as compared to PG 64-25 of national refinery, Karachi. PG 64-25 of national refinery, Karachi shows the maximum value (comparing all the temperatures at frequency of 0.1Hz), of phase angle in RTFO aged at temperature of 10^{o}C compare to PG 64-22 Uzbekistan.

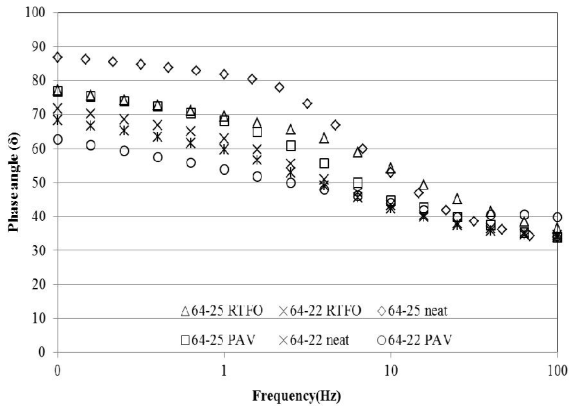

Figure 4. Influence of frequency sweep on phase angle at 30^{o}C for PG 64-25 & PG 64-22.

PG 70-22 of Attock refinery with PAV aged type has the higher values of G* at temperature of 10^{o}C as compare to PG 58-22 and PG 64-25 & PG 64-22. Comparing the all PG Grades, it is obvious that minimum value of phase angle is found in PG 64-22 of Uzbekistan at temperature of 10^{o}C in RTFO aged sample. If three PG Grades of national refineries i.e. PG 58-22 (A), PG 64-25 and PG 70-22 are compared, an increase is found in values with increase in the PG Grade. Figure 5 shows the relationship of PG Grade and complex viscosity

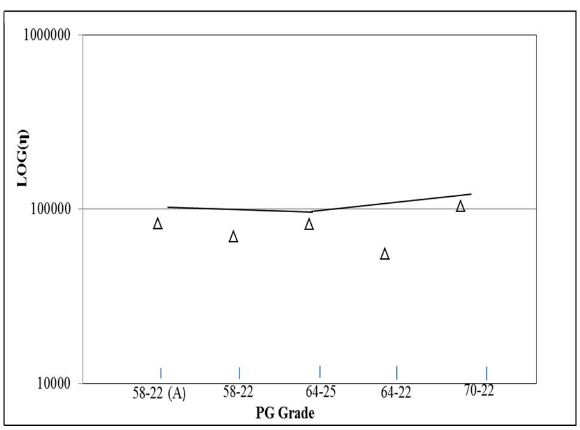

Figure 5. Influence of PG Grade on complex viscosity

Influence of frequency level on complex viscosity has been presented in Figure 6. The plots show nonlinear trends and viscosity decreases with an increase in frequency range of 0.1Hz to 100Hz.

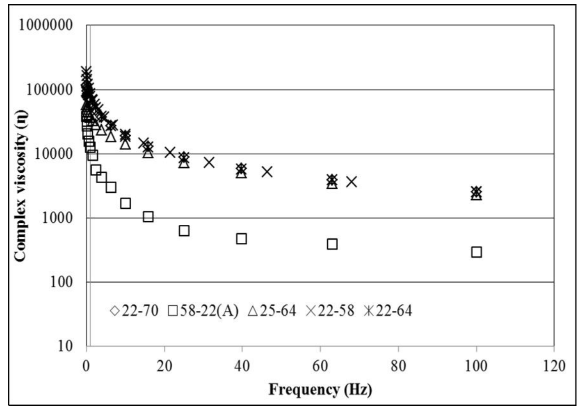

Figure 6. Influence of frequency sweep on complex viscosity (η)

PG 70-22 of Attock refinery, PAV aged show maximum value of complex viscosity at 10^{o}C and PG 58-22 of Attock refinery, neat shows the minimum value of complex viscosity at 70^{o}C, when all the PG Grades, all temperature and asphalt binder types are compared at frequency of 0.1Hz. The influence of temperature sweep on complex modulus and complex viscosity has been presented in Figure 7 and Figure 8, respectively. PG 58-22 of Attock refinery in comparison with other asphalt binders shows lower values of modulus. PG 64-22 of Uzbekistan shows the higher value of G* as compare to PG 64-25 of national refinery Karachi. PG 58-22 of UAE shows high values of complex viscosity (with maximum value at 10^{o}C), as compared to PG 58-22 of Attock refinery whereas PG 64-25 of National refinery shows higher values of viscosity as compare to PG 64-22 of Uzbekistan refinery.

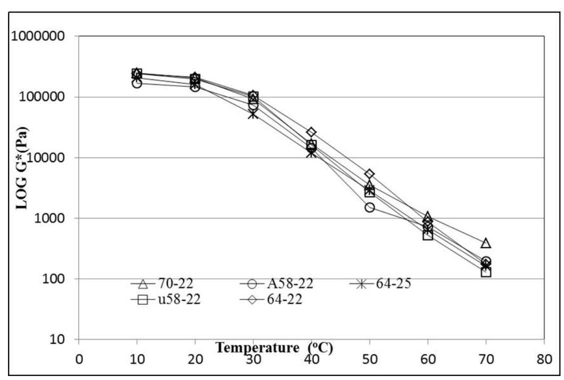

Figure 7. Influence of temperature sweep on complex modulus (G*)

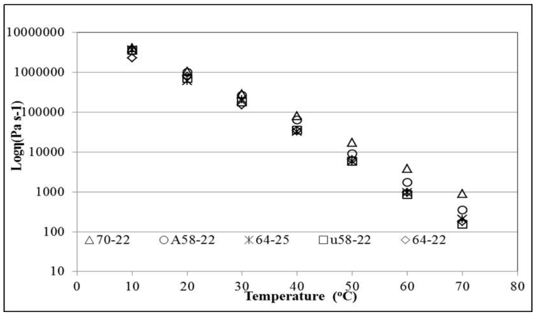

Figure 8. Influence of temperature sweep on complex viscosity (η).

3.1.1 Han's diagram

Han's diagram is a plot which shows the changes in elastic and viscous components of the complex modulus, when plotted at each temperature for any asphalt binder. Han's diagram interprets the relative elasticity or viscosity of an asphalt binder over the range of temperatures. Typical trends show that at high temperatures, asphalt behaves like a viscous material, and at the low temperatures asphalt binders behave like elastic materials and viscosity is lower. If a straight line is plotted such that G' = G", its intercepts with the Hans curves shows the crossover frequency between G' and G". Right side of the line and under the straight line shows the viscous or loss modulus behavior dominating in the sample, similarly left side and over the straight line shows the elastic component or storage modulus dominating the behavior of asphalt binder, in the Han's plot (Sulemani, 2009). Figure 9 depicts similar behavior of almost all the asphalt binders, irrespective of their source of manufacturing. However, at low frequency level, or at high temperature levels, the loss modulus is dominating on all the asphalt binders. It may be noted that increase in the value of both the modulus is mainly due to increase in the stiffness of asphalt binders, which is basically due to the high frequency levels or low temperatures levels.

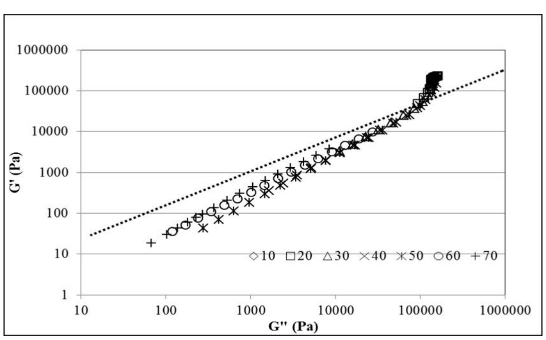

Figure 9. Typical Han's diagram PG 70-22 RTFO aged

3.1.2 Black diagram

Black space diagram is the plot of Log G* versus phase angle (δ) at different test temperature and frequencies. Usually, predictable viscoelastic behavior shows a decreasing phase angle and increasing complex modulus as the temperature decreases. All the asphalt binders show the same behavior on constructing the Black space diagrams with a slight different manner as the above typical figure illustrates.

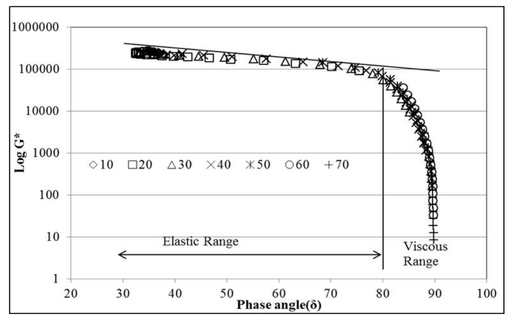

Figure 10. Typical Black space diagram PG 58-22 RTFO aged

Table 2. Results of Han's Diagram and Black Diagram

Binder Type	Hans Diagram Results		Black diagram Results	
PG Grade	Elastic Dominating	Viscous Dominating	Linearity	Thermo graphically Simple/ Complex
70-22 neat	Elastic	-	Linear	Complex
70-22 RTFO	Elastic	-	Non Linear	Complex
70-22 PAV	Elastic	-	Non Linear	Complex
58-22A Neat	Elastic	-	Linear	Simple
58-22A RTFO	-	Viscous	Linear	Complex
58-22A PAV	Elastic	-	Non Linear	Complex
64-25 neat	-	Viscous	Linear	Simple
64-25 RTFO	Elastic	-	Linear	Simple
64-25 PAV	Elastic at low	Viscous at high	Linear	Simple
58-22 neat	Elastic	-	Linear	Simple
58-22 RTFO	Elastic	-	Linear	Simple
58-22 PAV	-	Viscous	Non Linear	Complex
64-22 neat	Elastic	-	Linear	Simple
64-22 RTFO	Elastic	-	Linear	Simple
64-22 PAV	Elastic	-	Non Linear	Complex

3.2 Multi-Stress Creep Recovery Test

Multi stress creep recovery testing was conducted on virgin, RTFO and PAV aged asphalt binders using DSR. The asphalt binders for the

MSCR test were prepared using 25 mm plates. Asphalt binder specimen was heated to sufficiently flow to pour into a mold and sample was prepared using the silicone rubber mold. A pellet was form and used for test. The requirements for the temperature control were followed according to the AASHTO T 315. The asphalt binders were tested for different temperatures and stress levels. The temperature ranges between 10 to 70°C and stress ranges between 25 Pa to 25600 Pa (D' Angelo, 2010). Creep test is designed to identify the presence of elastic response in a binder and the change in elastic response at different stress levels while being subjected to ten cycles of creep stress and recovery. Non-recoverable creep compliance has been shown to be an indicator of the resistance of an asphalt binder to permanent deformation under repeated load (AASHTO TP 70, 2010). Behavior of each asphalt binder creep compliance (Jnr), Creep response and % binder recovery was studied. Results were elaborated with the help of plot against different parameters. Comparisons of results were shown at 10°C, 30°C and 70°C.

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

Creep compliance (Jnr) values, determined at stress levels have been presented in Figure 11-13. It may be noted from Figure 11-13 that creep compliance values of same grade of asphalt binders taken from different source are different. Low temperature and stress levels have relatively less significant effect on the Jnr values. It was also observed that asphalt binder with lower performance grade have higher tendency to recover at lower stress and temperature. The lower the Jnr value, the tendency of the asphalt binders to return back to its original shape is more and vice versa.

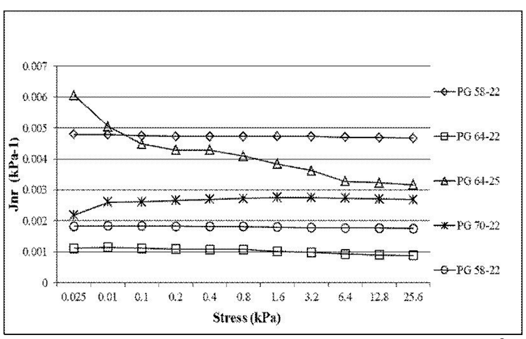

Figure 11. Influence of stress level on J_{nr} at 10°C

Similarly, general trends of asphalt binders under all temperatures have been presented in Figure 14. It may be noted from Figure 14 that creep compliance increases with an increase in temperature value. However, above 50°C, there is a gradual increase in the value of creep compliance.

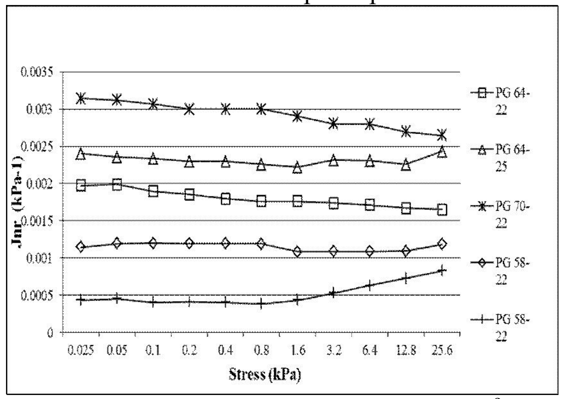

Figure12. Influence of stress level on J_{nr} at 30°C

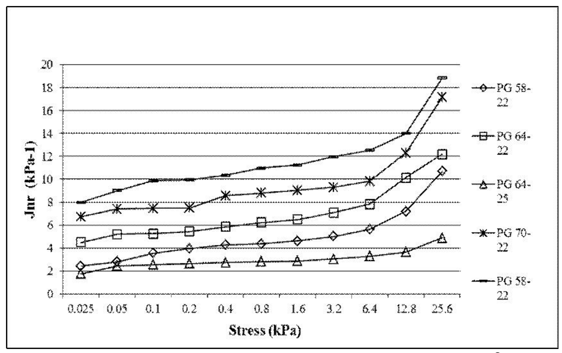

Figure13. Influence of stress level on J_{nr} at 70°C

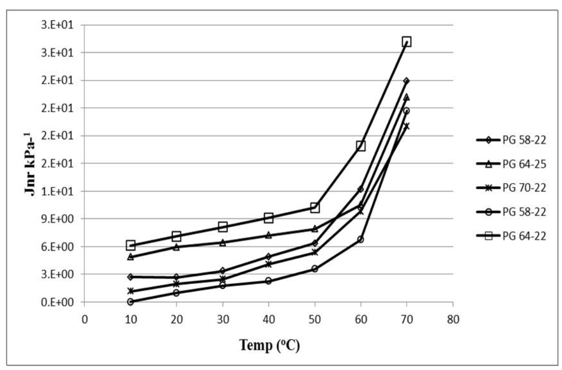

Figure14. Influence of Temperature on Jnr

The above figure shows that creep compliance is a function of temperature. At low temperature Jnr value are nor significant for all the asphalt binders. As we increase temperature, Jnr values increases. Above 50°C, these values increases abruptly showing larger values of Jnr. Larger the values of Jnr, % binder recovery will be less. The maximum percentage increase in the Jnr values beyond 50°C was observed for binder PG 64-22 and minimum was observed for binder PG 70-22.

3.2.2 Elastic response of asphalt binders

Elastic responses of asphalt binders at different temperatures were determined from Jnr values as shown in Table 3. The elastic response for each asphalt binder was confirmed according to the specification of AASHTO TP 70-10. The graph if the plotted point falls above the line, it shows that the asphalt binder is modified with an acceptable elastomeric polymer or in case of neat asphalt binder have sufficient elastic response at that temperature. Following table shows the elastic response of asphalt binders at all the temperature.

Table 3. Elastic response of asphalt binders

Asphalt binder	Temperature (°C)						
	10	20	30	40	50	60	70
PG 58-22	✓	✓	✓	✓	X	X	X
PG 64-25	✓	✓	X	X	X	X	X
PG 58-22	✓	✓	✓	X	X	X	X
PG 70-22	✓	✓	✓	✓	✓	✓	✓
PG 64-22	✓	✓	✓	✓	✓	X	X

✓ = Asphalt binders have been modified with Sufficient polymer or in case of neat asphalt; binder has sufficient elastic response at a particular temperature.

X = Asphalt binder have not been modified with optimum level of polymer or in case of neat samples; do not show sufficient elastic response at a particular temperature.

3.2.3 MSCR Binder Specification

New MSCR binder specification uses the %age recovery calculated for the asphalt binders. The Jnr values at 3.2 kPa shear stress using the MSCR test were calculated at different temperatures (10 to 70°C). This value was used to evaluate the type of traffic i.e. Standard (S), Heavy (H) and Very heavy (V) under which the asphalt binder can be used at a particular temperature (Wasage et al, 2011). For a specific temperature if the Jnr value of a sample at 3.2 kPa is less than 4, it can be used under standard traffic. If the Jnr value is less than 2, it can be used under Heavy traffic and if the value is less than 1, it can be used under Very heavy traffic loading. The corresponding values of Equivalent Single Axle Loads (ESAL) for various type of traffic i.e Standard (S), Heavy (H) and Very heavy (V) under which the asphalt sample can be used at a particular temperature are:

S = Standard < 10 million ESALs and standard traffic loading

H = Heavy 10 – 30 million ESALs or slow moving traffic loading

V = Very Heavy > 30 million ESALs or standing traffic loading

Figure 15 shows that the asphalt binder PG 70-22 can be used for very heavy traffic loading even at 50°C. Asphalt binder PG 58-22 can only be used for standard type of traffic loading. PG 58-22, PG 64-25, PG 64-22 can be used for heavy traffic loading at 50°C.

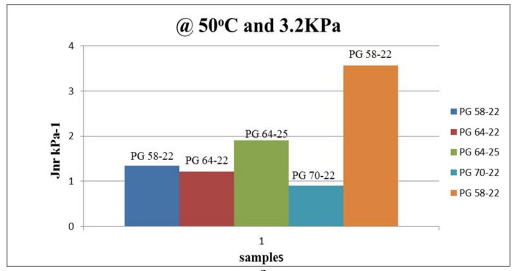

Figure 15. Jnr values @ 50°C and 3.2 kPa

3.2.4 Stress sensitivity of Asphalt binders

A stress sensitivity calculation as shown in Table 4 determines the increase in Jnr value as the stress levels increases from 0.1 to 3.2 kPa. If the percent increase in Jnr at 3.2 kPa was more than or equal to 75% of the Jnr at 0.1kPa. Then the binder was stress sensitive and vice versa. The requirement to keep the percent increase in Jnr below 75% was to ensure that the binder would not be overly stressing sensitive to unexpected heavy loads or unusually high temperatures.

Table 4. MSCR Binder Specifications

Binder grade	Suitable traffic loading	Upper stress sensitivity limit	Suitable temperature limit for all type of loading
PG 58-22	V	50°C	70°C
PG 64-25	V	50°C	60°C
PG 58-22	V	50°C	60°C
PG 70-22	V	70°C	60°C
PG 64-22	V	50°C	60°C

4. Conclusion

Following conclusions have been drawn from this study:

- Asphalt binders behave like elastic material at low temperature and like viscous materials at high temperature. Complex shear modulus decrease with the increase in temperature and decreases with the decrease in frequency. Phase angle increase with an increase in temperature and decreases with an increase in frequency level.
- Polymer modified asphalt binder showed improve elastic properties as compared with

neat asphalt binders. Polymer modified asphalt binders are least susceptible to temperature variations.

- Non-recoverable creep compliance (Jnr) increases with the increase in temperature and stress levels. All the neat binders do not meet the requirement of high temperature except polymer modified asphalt binder.
- Asphalt binder of same performance grades collected from different source showed different creep compliance and stress sensitivity.

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