Investigating the Performance of Conventional Asphalt Binders

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Abstract

Among various kind of distresses, rutting and fatigue are two major ones which affect the functional and structural performance of the flexible pavement significantly. Despite the popularity of different modified binders, conventional binders are largely used in the construction of low to moderate traffic volume roads. This paper aims at studying the performance of conventional asphalt binders with respect to their rutting and fatigue behaviour by using the Multiple Stress Creep and Recovery (MSCR) and Linear Amplitude Sweep (LAS) test respectively. In the study three conventional binders i.e. VG-10, VG-20 and VG-30 are tested over a range of temperature and loading conditions. Based on the experimental results, comparisons are made, and conclusions are given.

*Keywords:*Conventional asphalt binders, Linear Amplitude Sweep (LAS) and Multiple Stress Creep and Recovery (MSCR)

1. Introduction

Despite the popularity of modified binders, in developing countries like India, viscosity graded conventional binders are still widely used for the construction of low to moderate traffic volume roads such as majordistrict roads, other district roads, village roads etc. Rutting and fatigue are two major distresses which affect the structural and functional performance of the flexible pavement significantly. In hot to moderate climatic countries like India these two present more severe threat to flexible pavement as compared to low temperature cracking. Although bitumen contributes a very small part in the bituminous mixtures, but its properties affect the performance of the pavements considerably (Singh and Kumar, 2016).

Over the years a plethora of studies have examined the performance of the asphalt binders using different experimental methods and parameters.One of the most widely

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used methods/parameters for studying the rutting and fatigue performance of the asphalt binder are suggested by SHRP in superpave specification. But many of the studies have reported their inability to characterize the performance of the asphalt binders effectively (Biro et. al, 2009; D'Angelo, 2009a; D'Angelo, 2009b; D'Angelo, 2010). SHRP suggests using G*/Sinδ for examining the rutting properties of the asphalt binders but due to its limitations, researchers have worked on different methods to precisely predict the rutting resistance of conventional as well as modified binders. In 2001, National Cooperative Highway Research Program (NCHRP) introduced a new method repeated creep recovery. D'Angelo (2009a), worked further on it and developed Multiple Stress Creep and Recovery (MSCR) test. MSCR has advantage over other tests as it measures stress sensitivity, recoverable strain along with non-recoverable strain. Results have shown that, MSCR test results correlates well with the actual field performance (Bahia et. al, 2001; D'Angelo, 2009b, D'Angelo, 2010).

For quantifying the fatigue resistance of asphalt binders, SHRP gave parameter G*.Sinδ which is based on the principle that on the application of stress, lower dissipated energy per loading cycle (π.γ02.G*.sinδ) will result in lower damage to binder properties. So, for better fatigue resistance binder should possess minimum G*.Sinδ value. But this is based on the assumption that in flexible pavements, binder experiences lower strain levels so perform in linear viscoelastic (LVE) regions only, but many studies have clearly concluded that due to the differences in the stiffness of binder and aggregate, binder experiences non LVE strain even at lower strain values. So, parameter and the test procedure given by SHRP is not able to capture the complicated fatigue behaviour of the asphalt binder at higher strain levels over a wide range of frequencies. Various researchers have worked to develop different methods to precisely quantify the fatigue resistance of the binders. One such newly developed test procedure is Linear Amplitude Sweep (LAS) test. It is based on the principal of continuum viscoelastic damage. A number of studies have concluded its superiority over other traditional methods for evaluating the fatigue damage of asphalt binders (Anderson et. al, 2001; Hintz and Bahia, 2013; Hintz et. al, 2011).

The present study aims at studying the rutting and fatigue performance of the conventional asphalt binders with the help of MSCR and LAS test respectively. These tests were performed on three conventional binders over a range of temperature and stress levels. Test results of all the binders were compared and based on that conclusions are given.

2. Materials and experimental procedure

The study includes three conventional asphalt binders i.e. VG-10, VG-20 and VG-30. These are conventional (unmodified) binders. Grades of the used bitumen are based on Viscosity grading (According to IS-73:2013 specifications). Viscosity grade is defined on the basis of viscosity of the bitumen at 60 ºC. This is different from the performance grade (PG) specification where the requirement of physical property remains same for all the grades, but the temperature at which these properties must be achieved varies depending on the climate in which the binder is to be used.

Initially, the binders were characterized using conventional tests (i.e. penetration test, softening point test and ductility test). High temperature performance grades of the binders were then determined. The MSCR test was performed on the samples at four different stress levels. Apart from two standard stress levels of 0.1 and 3.2 kPa as specified in ASTM D7405-15, two higher levels of 5.0 and 8.0 kPa were also included to investigate the binder behaviour under higher stress levels. As rutting is a high temperature pavement distress, MSCR test was conducted at 40-70 ºC using 25 mm parallel plate diameter with 1 mm gap between the plates. During the MSCR, a constant stress is applied for 1 second followed by a recovery period of 9 seconds. Ten cycles of creep and recovery at each of the stress levels were applied without any rest periods between the cycles. Fatigue cracking occurs at intermediate to lower temperatures, So LAS test was performed at 10-30 ºC. As given in the standard AASHTO TP 101-14,first, frequency sweep test was performed by employing an 0.1% strain over a range of frequencies from 0.2 to 30 Hz. After frequency sweep, amplitude sweep is performed on the same sample. During amplitude sweep, frequency was kept constant at 10 Hz and the strain amplitude was linearly increased from 0 to 30%. 8 mm diameter spindle with 2 mm gap between the plates was while performing the test. For both LAS and MSCR, test sample was discarded after testing it for a single temperature and a new sample was used for next temperature.

3. Results and discussion

Results of conventional tests conducted on the binders are given in Table 1. As it can be seen, VG-30 is the harder grade bitumen followed by VG-20 and VG-10. Ductility values were found to be greater than 100 for all the samples. High temperature performance grade (PG) indicates the temperature upto which binder will be able to perform satisfactorily.Here PG of VG 20 and VG 30 was found to be the same i.e. PG 70-XX but the failure temperature of both the binders were 70.8 and 75.9 respectively.

Table 1: Conventional Properties of Asphalt Binders

Sr. No.	Properties	VG-10	VG-20	VG-30
1.	Penetration Values (As per IS:1203)	94	65	55
2.	Softening Point (ºC) (As per IS:1205)	46	48	50
3.	Ductility Value (As per IS:1208)	>100	>100	>100
4.	High Temp. PG (As per AASHTO R29)	PG 64-XX	PG 70-XX	PG 70-XX

3.1 Rutting performance

The results of MSCR are discussed broadly based on two parameters: percent recovery (E_r) and non-recoverable creep compliance (J_{nr}). Typical creep and recovery of binder during a MSCR test is shown in Figure 1 below:

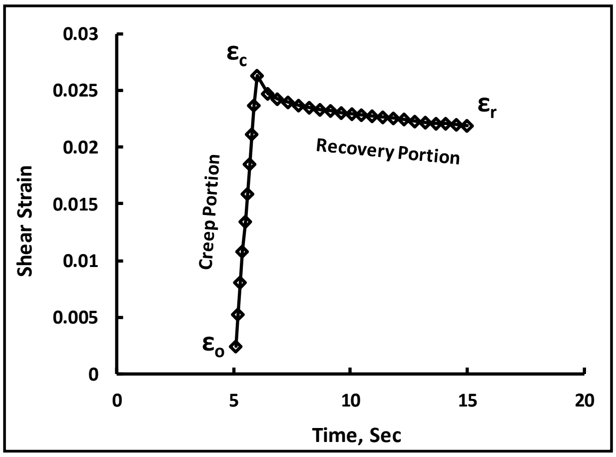

Figure 1: Typical Creep and Recovery Diagram

Difference between the initial strain (ε_o) value at the beginning of each creep portion and at the end of creep portion (ε_c), is known as adjusted strain (ε_1). Similarly, the difference between strain at the end of recovery period (ε_r) and ε_o is known as adjusted strain value at the end of recovery portion (ε_{10}). First, values of ε_1 and ε_{10}were calculated. Then by using following formulae values of percent recovery (E_r) and non-recoverable creep compliance (J_{nr}) were calculated.

$$\varepsilon_1 = \varepsilon_c - \varepsilon_0 \tag{1}$$

$$\varepsilon_{10} = \varepsilon_r - \varepsilon_0 \tag{2}$$

The average percent recovery at all the stress levels was calculated as

$$E_{\mathrm{r}}(\sigma) = sum(\varepsilon_r(\sigma, N)) / 10 \tag{3}$$

where,
$$\varepsilon_r(\sigma, N) = \frac{(\varepsilon_1 - \varepsilon_{10}).100}{\varepsilon_1} \tag{4}$$

Similarly, the average non-recoverable creep compliance was calculated as

$$J_{\mathrm{nr}}(\sigma) = sum(J_{\mathrm{nr}}(\sigma, N)) / 10 \tag{5}$$

where,
$$J_{\mathrm{nr}}(\sigma, N) = \varepsilon_{10} / \sigma \tag{6}$$

Percent recovery is a parameter which shows the instantaneous as well as delayed elastic response of the binders. Binders with greater percent recovery are expected to show better rutting resistance as they recover more, hence lesser permanent deformation. E_r values of binders at different temperatures and stress levels are given in Tables 2:

Table 2: E_r Values of Asphalt Binders

Binder	Temperature (°C)	Stress Level (kPa)			
		0.1	3.2	5	8
VG 10	40	19	11	11	8
	50	10	3	2	0
	60	8	0	-1	-1
	70	5	-3	-5	-5
VG-20	40	31	22	21	19
	50	15	8	6	4
	60	10	1	0	0
	70	6	-2	-3	-3
VG 30	40	44	33	32	31
	50	20	13	11	8
	60	13	2	1	0
	70	6	-1	-2	-2

Observing the values, it was found that VG-30 had the highest E_r values followed by VG-20 and VG-10. This trend was observed at all temperatures and stress levels. At higher temperature >=60 ºC and higher stress levels i.e. >=5.0 kPa, binders showed negative recovery values. This may be due to the tertiary creep behaviour which makes the binder flow even after the removal of the applied stress. This behaviour was more dominant at higher temperature and higher stress levels. This can also be due to the problems associated with the rheometer which do not unload the stress as fast as is desired and a small value of stress prevails. Even this small stress issufficient to give negative recovery values especially in case of conventional binders. Similar results have been reported in other studies also (Saboo and Kumar 2015, Soenen et al. 2013, Singh et al. 2017).

Percent recovery (E_r) values decreased with increase in stress levels while this relationship reversed with temperature, higher percent recovery values were obtained at lower temperatures. $E_r$values of binders at different stress levels are are graphically presented in figure 2.

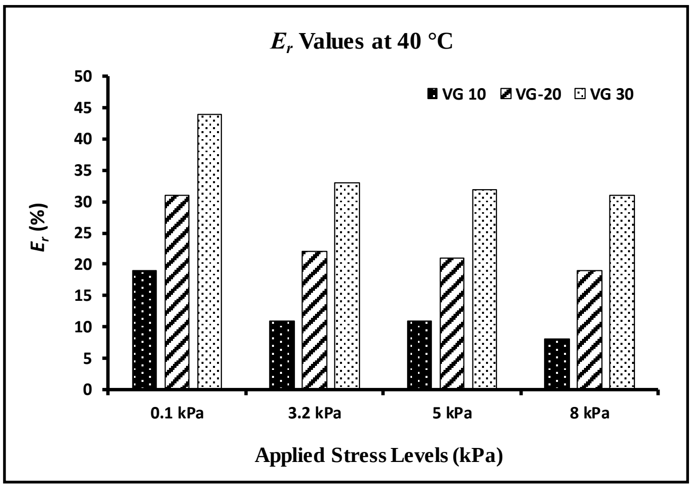

Figure 2: E_r Values of Binder at Different Stress Levels

Non-recoverable creep compliance is a measure of amount of residual strain left in the binder after the recovery period i.e. permanent strain. So lowerJ_{nr}values represents better rutting resistance properties of the binder. J_{nr} values of the binders at different temperatures and stress levels are given in Tables 3 respectively.

Table 3: J_{nr}Values of Asphalt Binders

Binder	Temperature (°C)	Stress Level (kPa)			
		0.1	3.2	5	8
VG 10	40	0.19	0.21	0.22	0.23
	50	0.77	0.87	0.90	0.94
	60	2.86	3.38	3.56	3.66
	70	9.91	11.88	12.42	13.38
VG-20	40	0.11	0.12	0.12	0.13
	50	0.47	0.53	0.55	0.57
	60	1.87	2.22	2.33	2.42
	70	6.69	8.02	8.37	9.02
VG 30	40	0.03	0.04	0.04	0.04
	50	0.23	0.25	0.26	0.28
	60	1.12	1.33	1.39	1.49
	70	4.31	5.19	5.38	5.83

Observing the test results it wasseen that VG-30 had the lowest J_{nr} values. VG-20 values were greater and VG-10 had the highest values. It translates that VG-30 has best rutting resistance among these conventional binders, followed by VG-20 and VG-10. The same trend was observed with E_r values also. J_{nr} values increased with increasing temperature and stress levels. This trend was observed for all three binders and all the testing conditions without any exception. J_{nr} values of binders at different stress levels are graphically presented in figure 3.

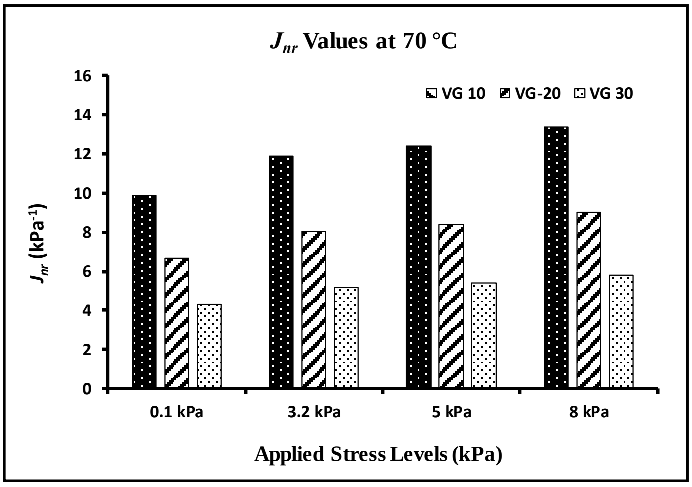

Figure 3: J_{nr} Values of Binder at Different Stress Levels

So, based on the MSCR test results, it can be concluded that among conventional asphalt binders VG-30 possesses greater rutting resistance which can be contributed to its higher stiffness which decreases the overall deformation under the application of load and higherelasticity which reduces the permanent deformation. VG-10 was found to be least rutting resistance.

Asphalt Institute (AI) suggests maximumJ_{nr} value of 4 kPa^{-1} and minimum$E_r$value of 30% for the usage of asphalt binders in the construction of roads having standard traffic conditions (i.e. >10 million ESALs) and standard traffic loading but from the results it can be observed that conventional binders are not suitable to use in hot climatic areas even with standard traffic condition. Whereas performance grading of these binders indicates otherwise. So, it highlights the need of revising the current PG criteria.

3.2 Fatigue Performance

Analysis of LAS result was done using Viscoelastic Continuum Damage (VECD) approach of damage calculation. First results of frequency sweep dats was analysed and parameter α was calculated. By using the parameter, parameter *B* was obtained with the help of this simple relationship:

$$B = 2\alpha \tag{7}$$

In the second part, analysis of amplitude sweep data was analysed using damage calculation method and the parameter A was calculated. Finally, binder fatigue performance parameter $N_f$was obtained by using the following relationship:

$$N_f = A(\gamma_{max})^{-B} \tag{8}$$

Where, γ_{max} = the maximum expected binder strain for a given pavement structure (in %).

In VECD analysis fatigue life of the binders is dependent on the values of parameters α and A. Parameter A represents the changes integrity of the binder due to the accumulation of damage. For better fatigue performance, it is desirable that binder maintains its integrity during the test. If binder shows rapid decrease in the value of loss modulus, it represents loss of elastic properties and a lower value of A is obtained. On the other hand, α parameter in an indicator of the sensitivity of the asphalt binder to the strain level. A lower value of α would indicate lower strain susceptibility. So, for the better fatigue resistance, higher A values and lower α values are desired. Fatigue parameters of the binders are given in Table 4.

Table 4: Fatigue Parameters of Binders at Different Temperatures

Binder	**30 °C**		**20 °C**		**10 °C**	
	α	A	α	A	α	A
VG-10	0.82	1.92E+04	0.92	1.65E+04	1.03	1.24E+04
VG-20	0.84	1.86E+04	0.97	1.65E+04	1.06	1.19E+04
VG-30	0.90	1.87E+04	0.99	1.58E+04	1.11	1.17E+04

The value of $\alpha$was lowest for VG-10 followed by VG-20. VG-30 had the highest αvalues. These values decreased with increasing temperature. In case of A values, opposite trend was observed. VG-10 was found to has highest A parameter values followed by VG-20 and VG-30. Both these parameters indicate that VG-10 has better ageing resistance than VG-20 and VG-30. This can be credited to the lower stiffness value of VG-10 as compared to VG-20 and VG-30 which reduces accumulation of strain and helps binders to sustain repeated strain. Fatigue life of asphalt binders calculated using 2.5 kPa stress level is presented in Figure 4.

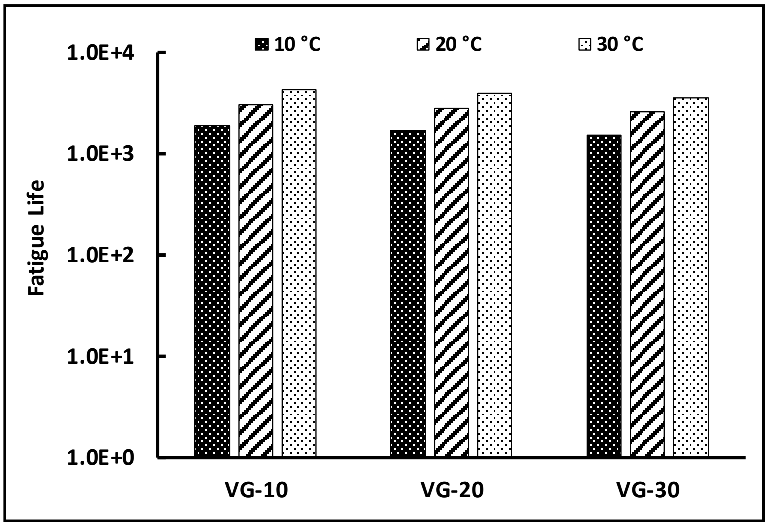

Figure 4: Fatigue Life of the Binders at Different Temperatures

4. Conclusions

The present study aimed at investigating the performance of conventional viscosity graded asphalt binders. Based on the rutting parameters (J_{nr} and E_r) obtained by MSCR test, VG-30 was found to have best rutting resistance followed by VG-20 and VG-10.On the higher temperatures and stress levels conventional binders were found to have zero to negative elastic recovery which makes them highly unsuitable for application in hot climatic areas with higher axle loads traffic. This was also found by comparing the results with the guidelines given by asphalt institute. In case of fatigue performance, results were totally opposite. Here VG-10 was found to perform better than VG-20 and VG-30. Fatigue life of all three binders decreased with decreasing temperature. These opposite trends of rutting and fatigue performance highlights the importance of using the binder as per the climatic conditions of the region.

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