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Rheological Performance of Asphalt Binders Under Different Creep and Recovery Periods in MSCR Test

Aniket V. Kataware [1] and Dharamveer Singh [1+]

Abstract: The present study was undertaken to evaluate the effects of creep and recovery periods on rheological responses and grading of the modified (polymer and crumb rubber modified) and unmodified binders in multiple stress creep recovery (MSCR) test. The MSCR test was conducted considering two creep periods (i.e., 1 and 2 seconds), three recovery periods (i.e., 9, 18, 27 seconds) and at three different temperatures (i.e., 52˚C, 64˚C and 76˚C). A total of 162 binder samples were tested in the laboratory using dynamic shear rheometer. The polymer modified binder showed increase in percent recovery (*R*) with an increase in a recovery period, while *R* value did not show variations with increasing creep recovery periods for the crumb rubber modified and unmodified binders. The stress sensitivity of modified binders showed mixed trend with an increase in creep recovery period. The effects of recovery period were minimal with longer creep period for modified binders. The grading based on AASHTO MP 19, could increase adequate traffic level of modified binders, when subjected to longer recovery time. The study shows that loading time in MSCR test may be relooked into for polymer and crumb rubber modified binders.

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***Key words**: Binder grade; Multiple stress creep and recovery; Non recoverable creep compliance; Percent recovery.*

Introduction

Recently, MSCR test has been developed to evaluate rutting performance and appropriateness of asphalt binders for different traffic loading conditions [1-6]. In this test, a binder sample is subjected to ten loading and unloading cycles with 1 second creep and 9 seconds recovery period (C1R9) at a selected stress level (i.e., 0.1 kPa or 3.2 kPa) and temperature. Then the rheological parameters namely, percent recovery (*R*) and non-recoverable creep compliance (J_{nr}) are estimated [1, 6]. A high *R* and low J_{nr} values are desirable for a strong and rut resistant binder. Many researchers have reported that J_{nr} has a good correlation with rutting distress of a flexible pavement and can be a promising test parameter in assessing quality of modified and unmodified binders [1, 6-9]. Further, the J_{nr} obtained from MSCR test can be utilized to grade a binder suitable for different traffic loading conditions in accordance with AASHTO MP 19 [10]. For example, a binder is appropriate for standard (S), high (H), very high (V) and extremely high traffic (E) loading conditions, if J_{nr} (kPa^{-1}) is in range of 2 to 4, 1 to 2, 1 to 0.5 and less than 0.5, respectively [10]. It can be seen that a desired value of J_{nr} decreases as traffic level increases. As traffic speed increases, loading time on a pavement decreases and vice-versa. The creep and recovery periods may vary depending upon the traffic conditions. For example, for extremely high traffic loading conditions where vehicles would be moving at low speed may result in a high loading time. The longer creep and recovery time simulate field traffic loading conditions for a pavement [11-13]. Diab, Aboelkasim, and Zhanping You (2014) recommended to use loading and rest period in such a way that the ratio of rest period to loading time is equal and greater than 10 [14]. It is expected that modified and unmodified binders may behave differently under longer creep and recovery periods, and hence the results obtained for C1R9 in accordance with ASTM D7405 [15] may not represent performance of asphalt binders in a better way. As reported by numerous researchers, modified binders may not recover fully when subjected to a 9 second recovery period, and thus can exhibit high J_{nr} [16-17]. Delgadillo et al. [17] reported that Elvaloy® modified binder could recover fully after recovery period of 1000 seconds. Similarly, Domingos and Faxina [11] evaluated response of unmodified and modified binder under two loading conditions: C1R9 and 2 second creep and 18 second recovery period (C2R18). They reported that for all binders, J_{nr} increases and *R* decreases when loading condition changed from C1R9 to C2R18. Also, PPA+SBS modified binder showed less sensitivity to increased recovery and creep period as compared to PPA and SBS modification alone[12]. Change in the *R* and J_{nr} could be possible under different creep and recovery loading time. Therefore, grading of a binder based on J_{nr} value obtained using C1R9 loading time has to be revised.

The objectives of the present study were to (1) evaluate the effects of creep and recovery periods under different temperatures on rheological responses (R and J_{nr}) of modified and unmodified binders, (2) determine grade of binders suitable for different traffic loading conditions based on J_{nr} in accordance with AASHTO MP 19 [10], and to evaluate change in grade of binders subjected to different creep and recovery periods. Three different binders namely, virgin, crumb rubber modified and polymer modified were used in this study. The study may be helpful in improving the guidelines of MSCR test methods and selection of a binder grade.

Experimental Plan and Test Procedure

[1] Transportation Systems Engineering, Department of Civil Engineering,Indian Institute of Technology Bombay Mumbai, India-400076.

[+] Corresponding Author: E-mail dvsingh@civil.iitb.ac.in

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Materials Collection

One unmodified binder, VG 30 which is equivalent to AC 30 grade of binder having absolute viscosity in range of 2400 – 3600 Poise at 60°C, and two modified asphalt binders, crumb rubber modified binder (CRMB 60) and polymer modified binder (PMB 40) were collected in this study. Base binder was modified with 11% crumb rubber (crumb rubber 100% and 80% passing from sieve number 30 and 80, respectively) and 3.5% SBS polymer to achieve CRMB 60 and PMB 40 binders, respectively. The number suffix with CRMB and PMB indicates grade of the binders based on softening and penetration values, respectively, designated as per Indian standard. The modified and unmodified binders selected in this study are commonly used in India for construction of flexible pavements. The use of CRM binder is quite popular in India because of utilization of waste tire materials. Usually modified binders (CRMB and PMB) are used for surface course for heavy traffic and region with high temperatures, and unmodified binder (VG30) is used for a base course of a flexible pavement. Basic properties of the binders used in current study are as shown in Table 1. The binders were found to be acceptable as per relevant Indian standards. Though both the binders differ in PG grading, they are recommended for similar site conditions. The selection of each of the binder depends on government policy and commercial use.

Laboratory Experimental Plan

The MSCR tests were conducted in accordance with ASTM D 7405 [15], considering two creep periods (1 and 2 second), three recovery periods (9, 18 and 27 seconds) under two stress levels (i.e., 0.1 kPa and 3.2 kPa).The Fig. 1 shows a laboratory test plan. Six different combinations of creep and recovery periods were used in this study: C1R9, C1R18, C1R27, C2R9, C2R18 and C2R27, where letter C indicates creep period and R shows recovery period. The C1R9 is the creep and recovery period as per ASTM D 7405 [15]. The MSCR testing was conducted at three different temperatures: 52˚C, 64˚C and 76˚C. Usually 52˚C and 64˚C temperatures are observed in India, while 76˚C temperature is being considered to see effect on binder's performance at extreme temperature. A wide range of creep and recovery periods, and temperatures were selected to evaluate their effects on rheological responses of modified and unmodified binders. The longer creep and recovery period could simulate field

Table 1. Basic Properties of Binders.

Tests	VG 30		PMB 40		CRMB 60	
	Observed Value	Limit as per IS 73	Observed Value	Limit as per IS 15462	Observed Value	Limit as per IS 15462
Penetration(1/10) mm, Min	43	45	49	30-50	32	<50
Softening Point in ˚C, Min	53.2	47	61.8	60	60.7	60
Ductility in cm, Min	>100	75	>100	-	20.4	-
Viscosity at 60˚C, Poise	2400	2400-3600	-	-	-	-
Viscosity at 135˚C, cst, Min	450	350	-	-	-	-
Viscosity at 150˚C, Poise	-	-	7.1	3-9	12.8	3-9
PG Grade as per ASTM D6373	PG 70-XX		PG 82-XX		PG 88-XX	

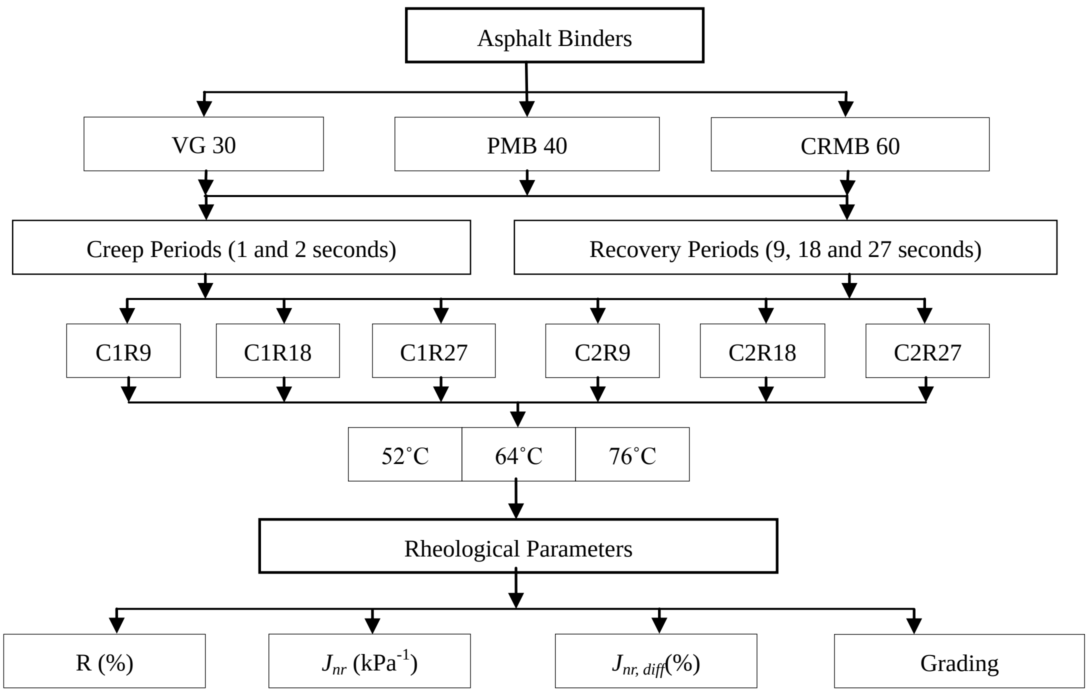


Fig. 1. Flow Chart for MSCR Testing.

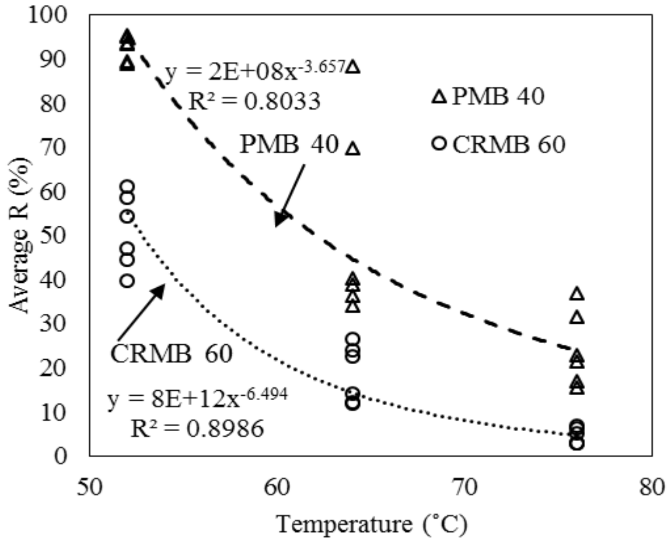


Fig. 2. Variation of Percent Recovery (at 3.2 kPa) with Temperature for Modified Binders.

traffic loading conditions for a pavement [11-13]. A total of 162 samples were tested in the laboratory (i.e., 2 creep periods x 3 recovery periods x 3 temperatures x 3 binders x 3 samples = 162). The MSCR tests were conducted using dynamic shear rheometer device, MCR 102 model from Anton Paar. The average results of three samples were reported in this study.

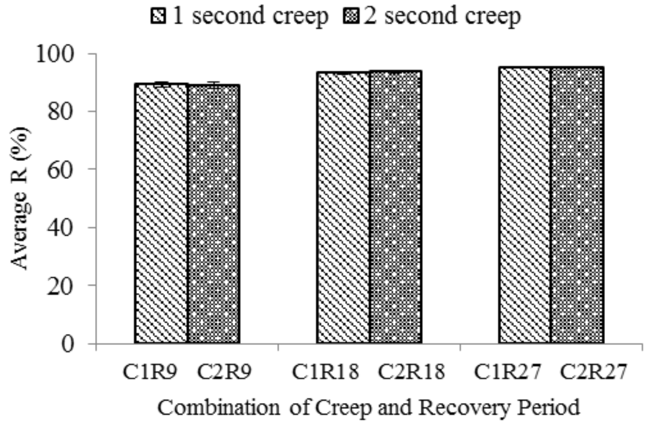
Results and Discussion

Effects of Creep and Recovery Period on Percent Recovery of Binders

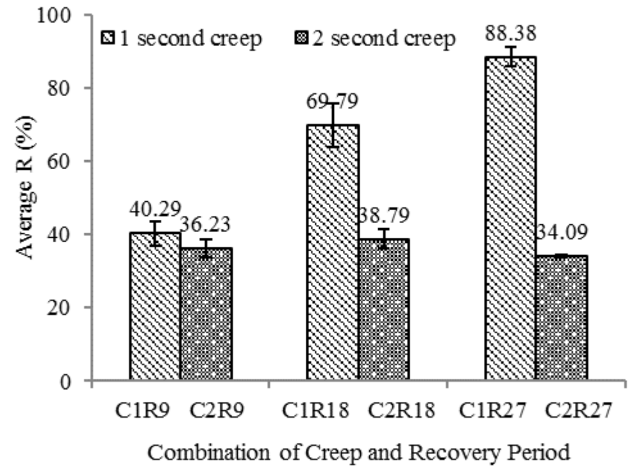
The unmodified binder (VG30) did not show any change in *R* with different recovery periods, hence results of VG 30 binder are not presented in this section. Thus, the effects of creep and recovery period are discussed only for modified binders (PMB 40 and CRMB 60).

The Fig. 2 shows plot of temperature and *R* for both the modified binders. The *R* decreases with an increase in temperature. The PMB 40 showed higher *R* than CRMB 60 binder at all test temperatures (Fig. 2). The Figs. 3 and 4 show plot of *R* (%) at 3.2 kPa for different creep and recovery periods for PMB 40 and CRMB 60 binders, respectively. The effects of recovery period on *R* changes with creep period and temperature for both the binders. The PMB 40 binder showed less reduction in *R* with an increase in temperature compared to CRMB 60 binder. For example, at C1R9, increase in temperature from 52˚C to 76˚C showed 75% and 90% reduction in *R* for PMB40 and CRMB 60 binders, respectively. A similar trend was observed for other combinations of creep and recovery periods.

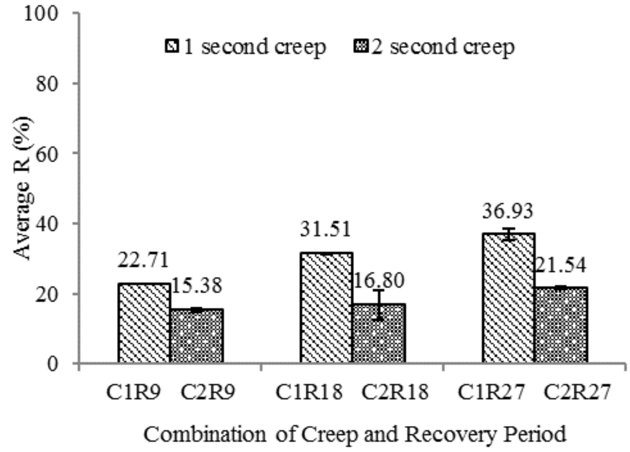
For PMB 40 binder, the effect of recovery period on *R* was negligible at 52˚C, irrespective of creep periods (Fig. 3(a)); indicating that increase in recovery period at lower temperature may not affect *R* of this binder. However, at elevated temperatures (i.e., 64˚C and 76˚C), a sample subjected to 1 second creep period showed significant increase in *R* with an increase in recovery period (Fig. 3(b) and Fig. 3(c)). For example, at 64˚C, increase in recovery



(a) Percent Recovery at 52˚C Temperature



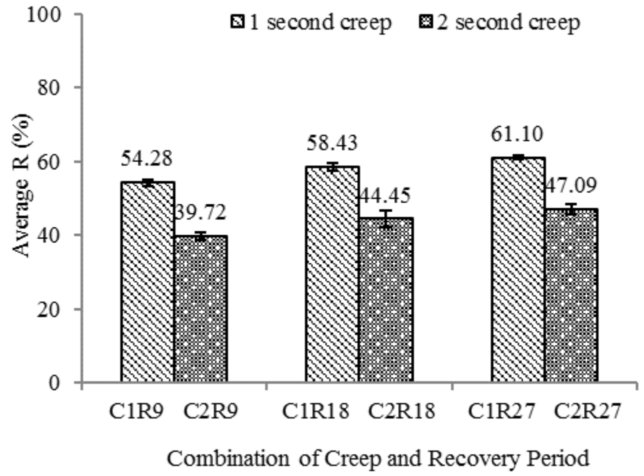
(b) Percent Recovery at 64˚C Temperature



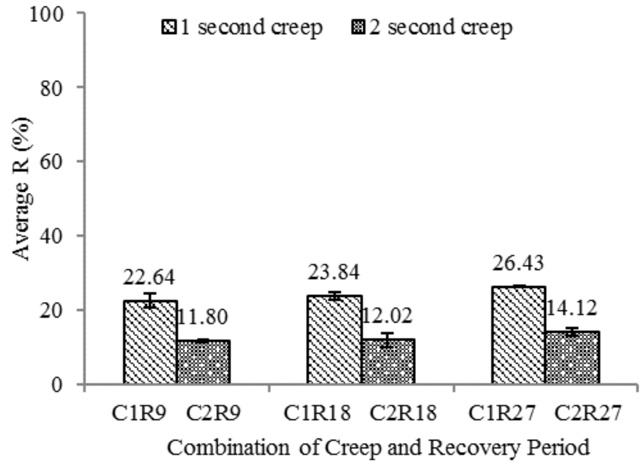
(c) Percent Recovery at 76˚C temperature

Fig. 3. Effects of Creep and Recovery Periods on Percent Recovery (at 3.2 kPa) for PMB 40.

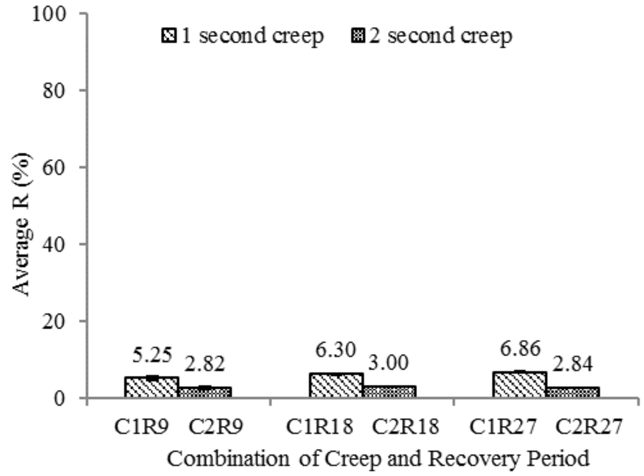
period from 9 seconds (C1R9) to 18 (C1R18) showed 73% increase in *R* value. Similarly, increase in recovery period from 9 seconds (C1R9) to 27 (C1R27) showed 119% increase in *R* value. The results show that recovery of polymer modified binder increases with an increase in recovery period at higher temperatures. This elastic behavior of PMB 40 binder may be due to presence of polymer which facilitates recovery with longer recovery period



(a) Percent Recovery at 52˚C Temperature



(b) Percent Recovery at 64˚C Temperature



(c) Percent Recovery at 76˚C Temperature

Fig. 4. Effect of Creep and Recovery Periods on Percent Recovery (at 3.2 kPa) for CRMB 60.

[11-13]. It is interesting to note that the effect of recovery period on *R* was not noticeable when a sample was subjected to 2 seconds creep, showing inability of polymer structure to recover when subjected to longer creep period. The CRMB 60 binder did not show any significant change in *R* with longer recovery periods at any of the selected temperatures and creep period (Fig. 4).

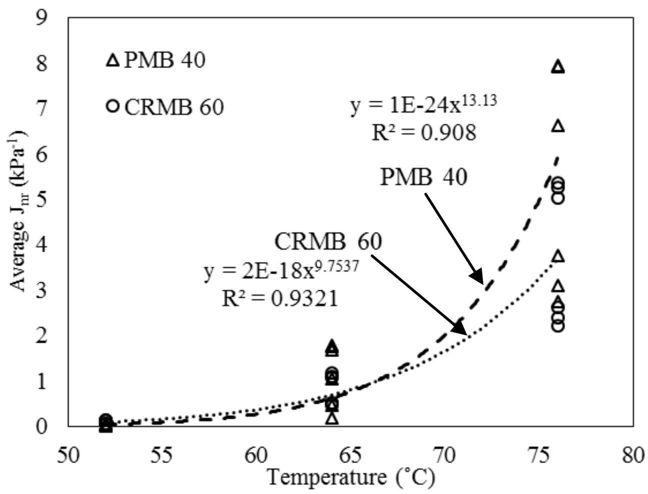


Fig. 5. Variation of J_{nr} (at 3.2 kPa) with Temperature for Modified Binders.

The effect of creep periods on *R* was also investigated for both the modified binders. The *R* decreases with an increase in a creep period for both PMB 40 and CRMB 60 binders, except at 52˚C, where PMB 40 binder showed equal *R* values for both the creep periods. It can be concluded that, a binder subjected to a longer creep period may need longer recovery period to recover.

Effects of Creep and Recovery Periods on Non recoverable Creep Compliance

The Fig. 5 shows a plot between temperature and J_{nr} value estimated at 3.2 kPa. The rate of change in J_{nr} with temperature is higher for PMB 40 compared to CRMB 60 binder. This indicates that polymer network gets influenced significantly with change in temperature. Both the modified binders showed similar J_{nr} values at 52˚C. However, at high temperature, CRMB 60 showed lower J_{nr} than that of PMB 40. The results show that CRMB 60 can be a stiffer binder; however, its elastic response may decreases rapidly.

The Fig. 6 shows a plot between J_{nr} and *R* for PMB 40 and CRMB 60 binders. The *R* for VG 30 binder was found to be minimal in range of 0 to 2%, therefore, the plot between J_{nr} and *R* is not plotted for this binder. The results show that *R* decreases with an increase in J_{nr} value. The rate of change in *R* is high for CRMB 60 compared to PMB 40. For same J_{nr} value, PMB 40 binder showed higher *R* than CRMB 60 binder. The AASHTO TP70 [18] provides a standard plot between J_{nr} and *R*, which can be used to identify presence of elastomeric polymer in a binder. The plot of a binder above the standard line indicates presence of acceptable elastomeric polymer, while a plot below the standard line shows insufficient elastomeric polymer. It can be seen from this plot that, at 52˚C, CRMB 60 shows response like a binder modified with elastomeric polymer; however, its elastic behavior diminishes rapidly at higher temperature and at longer creep period. For PMB 40, majority of the points are above the standard line, indicating presence of acceptable quantity of elastomeric polymer.

The Figs. 7 through 9 show plot of average J_{nr} (kPa^{-1}) at 3.2 kPa stress level for VG 30, PMB 40 and CRMB 60 binders, respectively. The J_{nr} increases with an increase in temperatures for all binders

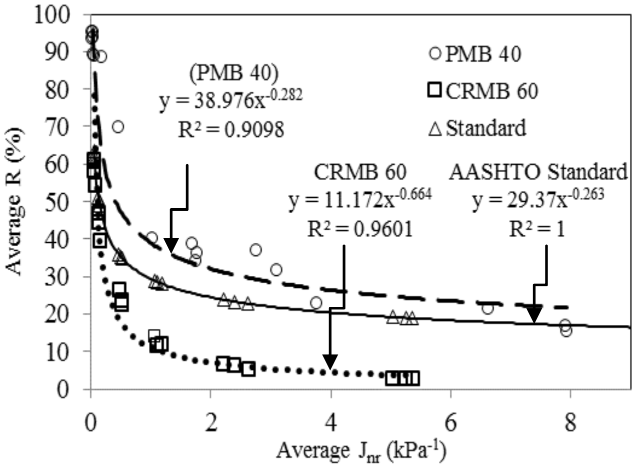
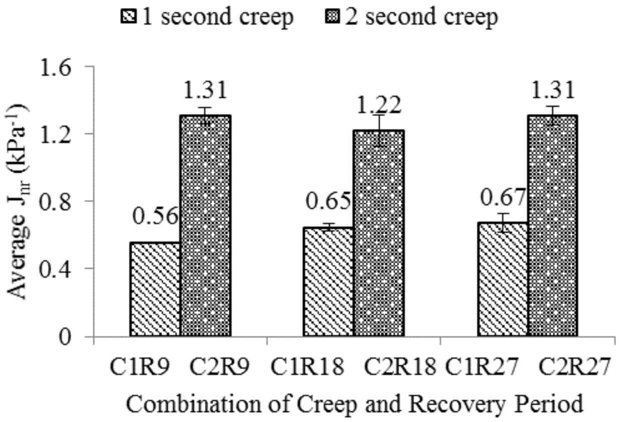


Fig. 6. The Plot between J_{nr} (at 3.2 kPa) and Percent Recovery (at 3.2 kPa) for Modified Binders.

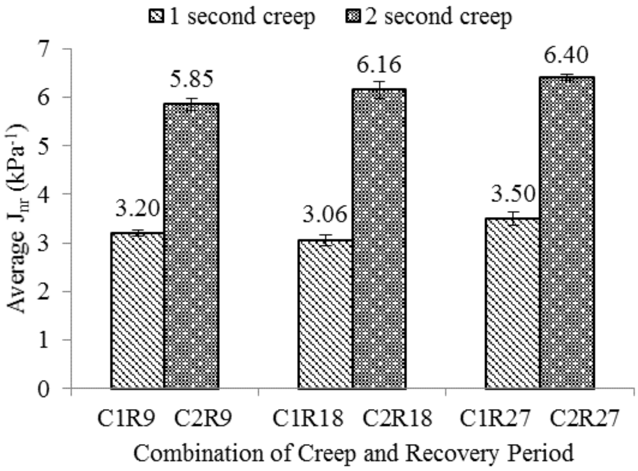
(Figs. 7 through 9), indicating higher rutting susceptibility of a binder at elevated temperatures. For example, at C1R9, increase in temperature from 52˚C to 76˚C showed increment in J_{nr} by 19 times (from 0.56 kPa^{-1} at 52˚C to 10.61 kPa^{-1} at 76˚C) for VG 30. For similar conditions, PMB 40 and CRMB 60 binder showed increment in J_{nr} by 94 times and 44 times, respectively. The change in J_{nr} with temperature is highest for PMB 40 followed by CRMB 60 and VG 30 binders. Similar trends were observed for C2R9.

The J_{nr} value for unmodified binder (VG 30) did not change with an increase in recovery period (Fig. 7). The results show that both modified binders (PMB 40 and CRMB 60) showed different behavior. The CRMB 60 showed negligible change in J_{nr} with longer recovery periods. On the other hand, PMB40 showed a decrease in J_{nr} with an increase in recovery period. For example, for PMB 40 binder, at 1 second creep period and at 52˚C, increase in recovery period from 9 (C1R9) seconds to 18 seconds (C1R18) resulted in approximately 40% decrease in J_{nr}. Similarly, increase in recovery period from 9 seconds (C1R9) to 27 seconds (C1R27) showed 55% decrease in J_{nr}. The decrease in J_{nr} was significant at 64˚C followed by 52˚C and 76˚C.The effect of recovery period was minimal at higher temperature (i.e. 76˚C). The results indicate that the present loading condition C1R9 may show low rut resistant property of this binder. However, the effect of recovery period on J_{nr} was not noticeable at 64˚C and 76˚C when a sample was subjected to 2 seconds creep. At 52˚C for 2 second creep, the PMB 40 works reasonably well under high creep period. This may be due to elastic behavior of PMB 40 [12-13].

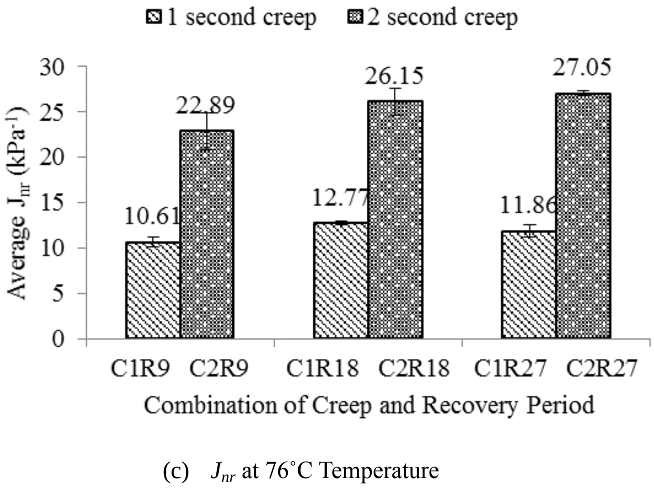
The effect of creep period on J_{nr} was also investigated for both unmodified and modified binders. The J_{nr} increases with an increase in creep period from 1 second to 2 second irrespective of recovery period. For example, increase in creep period from 1 second to 2 second resulte in 100% increase in J_{nr} value for both VG30 and CRMB 60 binders at all test temperatures and recovery periods. However, for PMB 40 binder, change in J_{nr} with creep period depends upon temperature. For example, at 52˚C and 9 seconds rest period, increase in creep period from 1 second (C1R9) to 2 seconds (C2R9) resulted in 56% increase in J_{nr} value (Fig. 8(a)). A similar trend was observed for rest period of 18 and 27 seconds (Fig. 8(a)).



(a) J_{nr} at 52˚C Temperature



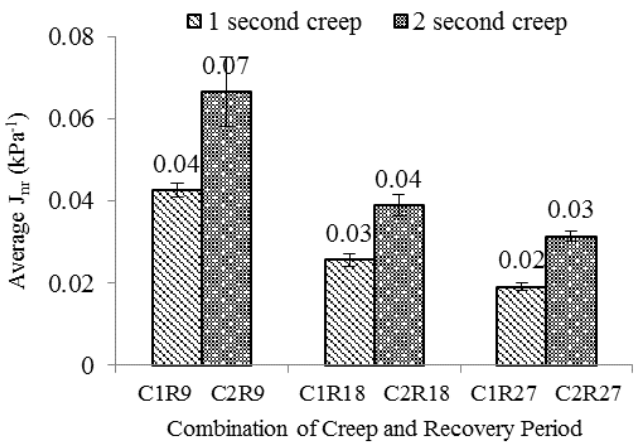
(b) J_{nr} at 64˚C Temperature



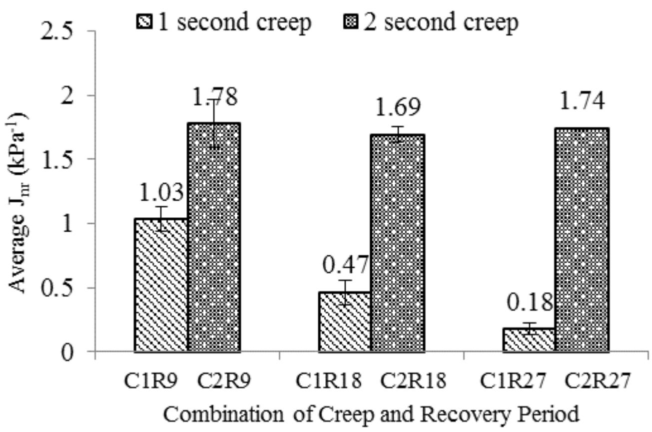
(c) J_{nr} at 76˚C Temperature

Fig. 7. Effects of Creep and Recovery Periods on J_{nr} Value (at 3.2 kPa) for VG 30.

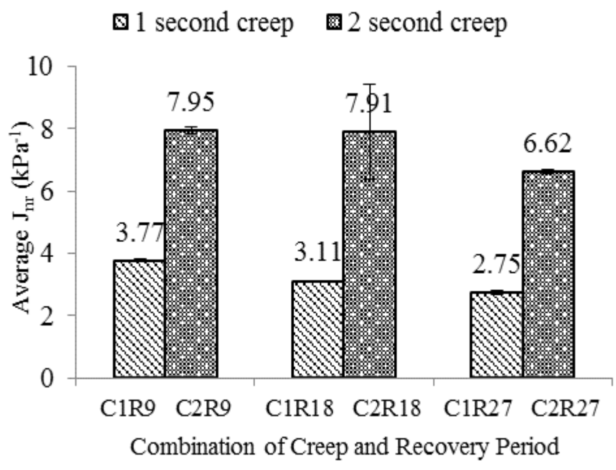
In fact, significant increment in J_{nr} was observed with an increase in creep period (Fig. 8(b) and Fig. 8(c)) at high temperatures (64˚C and 76˚C). The results show that a binder would exhibit higher permanent deformation at higher temperature when subjected to a longer creep period.



(a) J_{nr} at 52˚C Temperature

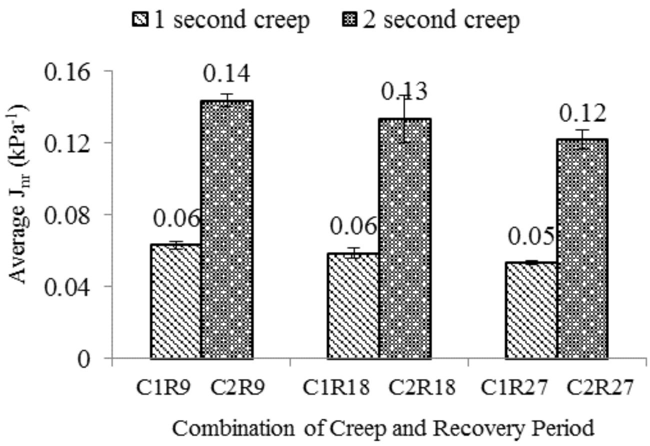


(b) J_{nr} at 64˚C Temperature

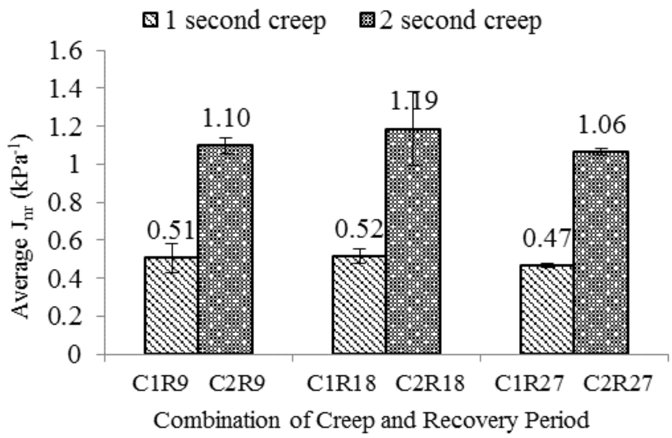


(c) J_{nr} at 76˚C Temperature

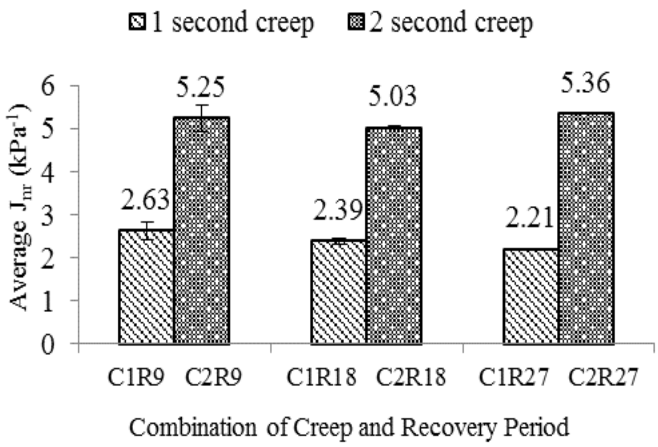
Fig. 8. Effect of Creep and Recovery Periods on J_{nr} Value (at 3.2 kPa) for PMB 40.



(a) J_{nr} at 52˚C Temperature



(b) J_{nr} at 64˚C Temperature



(c) J_{nr} at 76˚C Temperature

Fig. 9. Effects of Creep and Recovery Periods on J_{nr} Value (at 3.2 kPa) for CRMB 60.

Stress Sensitivity of Binders at Different Creep and Recovery Periods

The $J_{nr,diff}$ indicates stress sensitivity of a binder [11]. The AASHTO MP 19 [10] recommends that $J_{nr,diff}$ value for a binder should not be more than 75%. The Table 2 shows summary of $J_{nr,diff}$ for modified and unmodified binders estimated at different temperatures, creep and recovery periods. The PMB 40 binder passes AASHTO MP 19 [10] requirement of maximum $J_{nr,diff}$ of 75% when subjected to 1 second creep loading at 52˚C and 64˚C, while for similar loading conditions, the CRMB 60 binder fails to meet this criterion. Both the binders show $J_{nr,diff}$ higher than 75% at 2 second creep at higher

Table 2. $J_{nr,diff}$ for Modified and Unmodified Binders.

Binder	T (˚C)	Average $J_{nr,diff}$(%)					
		C1R9	C1R18	C1R27	C2R9	C2R18	C2R27
PMB 40	52	-50.3	-54.3	-53.3	-52.7	-59.9	-56.3
	64	74.4	57.3	24.9	120.5	132.2	123.5
	76	362.1	564.6	636.9	1212.7	1648.1	1677.5
CRMB 60	52	107.0	104.7	142.4	130.2	172.9	207.4
	64	260.8	342.4	358.0	251.3	271.7	303.7
	76	249.4	310.2	259.0	198.3	176.4	257.2
VG 30	52	4.4	7.0	9.6	2.8	1.7	4.5
	64	4.6	2.5	2.5	4.7	9.6	5.3
	76	6.7	1.0	5.3	3.0	2.4	2.2

temperatures (64˚C and 76˚C). The unmodified binder (VG30) showed $J_{nr,diff}$ less than 75%, indicating less sensitivity to stress. The temperature has significant influence on stress sensitivity of a binder. The $J_{nr,diff}$ increases with an increase in temperature. For example, for PMB 40 binder at C1R9, change in temperature from 64˚C to 76˚C, increases $J_{nr,diff}$ from 74.4% to 362.1%. At 52˚C, the PMB 40 was not observed to be stress sensitive irrespective of change in creep or recovery periods. It was found that at this temperature, the J_{nr} values at 0.1 kPa were lower than the J_{nr} values estimated at 3.2 kPa, hence a negative $J_{nr\text{-}diff}$ was calculated.

For PMB 40, at 64˚C, the $J_{nr,diff}$ decreases with an increase in recovery period for a sample subjected to 1 second creep period, indicating that this binder may show less sensitive to stress if the recovery period is increased. However, this decrease in J_{nr} with rest period was not observed for 2 seconds creep period. It means that at high creep period, PMB40 shows high $J_{nr,diff}$ irrespective of an increase in recovery period. At high temperature (i.e., 76˚C), the $J_{nr,diff}$ was found to be significantly high, indicating that binder is highly stress sensitive at this temperature. Interestingly, at high temperature (76˚C), stress sensitivity increases with an increase in rest period, which means that at high temperature and longer creep period, a polymer structure get damaged and could not recovery back in spite of providing longer recovery periods.

The CRMB 60 binders showed high $J_{nr,diff}$ at all the test temperatures. The $J_{nr,diff}$ for this binder increases with an increase in temperature, creep period, and rest periods. At 52˚C and 64˚C, stress sensitivity of CRMB 60 observed to be more as compared to PMB 40. However at 76˚C, PMB 40 was observed more stress sensitive as compared to CRMB 60. It can be concluded that both modified binders are stress sensitive and behave differently.

Grading of Binders for Different Traffic Loadings Conditions

As per AASHTO MP 19 [10], an asphalt binder can be graded into four categories as '*E*', '*V*', '*H*' and '*S*' based on J_{nr} value determined at 3.2 kPa. The grade '*E*', '*V*', '*H*' and '*S*' indicate that a binder is suitable for extremely high traffic loading (i.e., Traffic level ESALs > 30 million and. speed < 20 km/h), very high traffic loading (i.e., Traffic level ESALs > 30 million or speed < 20 km/h), high traffic loading (i.e., Traffic level ESALs = 10-30 million or speed 20-70 km/h), standard traffic loading (i.e., Traffic level ESALs< 10 million and speed > 70 km/h), respectively [10]. A binder with J_{nr} value in range of 0.0 to 0.5 kPa^{-1} will be considered suitable for extremely high traffic loading (i.e., ESALs > 30 million and < 20 km/h), and will have designation '*E*' with its name. For example, a PG70-22 binder tested at 70˚C will be graded as PG70E-22, PG70V-22, PG70H-22, and PG70S-22 for J_{nr} (kPa^{-1}) value in range of 0.0 to 0.5, 0.5 to 1.0, 1.0 to 2.0, and 2.0 to 4.0, respectively. A low value of J_{nr} is desired for extremely high traffic loading, and vice versa. It is to be noted that, the designation of binder primarily depends upon the J_{nr} value estimated at C1R9. As presented in above paragraphs, the modified and unmodified binders may behave differently with change in creep and recovery periods. Therefore, it is important to discuss effects of creep and recovery periods on grading of binders estimated based on J_{nr}. Since, the AASHTO MP 19 does not provide any designation for J_{nr} value greater than 4 kPa^{-1}, an additional category 'S^-' (material not suitable for paving purposes) is considered. The binders were assigned grade at different loading conditions: C1R18, C1R27, C2R9, C2R18, and C2R27, and their grade was compared with its reference grade estimated at C1R9 loading condition recommended by AASHTO MP 19. Table 3 shows grade of PMB40, CRMB60 and VG30 binders at different combinations of creep period, recovery period, and temperatures.

At standard creep and recovery periods (i.e., C1R9), both modified binders (PMB40 and CRMB60) were found to be suitable for '*E*' and '*S*' category at 52˚C and 76˚C, respectively. Whereas, at 64˚C, CRMB60 and PMB 40 binders were graded in '*V*' and '*H*' category, respectively. The VG30 binder was graded as *V, S,* S^- at 52˚C, 64˚C and 76˚C, respectively, indicating that this binder is not suitable for extremely high traffic conditions. The results show that as temperature increases the grade of a binder declines to '*S*' or lower (S^-).

At 52˚C, modified binders (PMB 40 and CRMB 60) showed '*E*' grade for all combinations of creep and recovery periods. However, at 52˚C, unmodified binder (VG 30) diminished by one grade from '*V*' to '*H*' when creep period was changed from 1 to 2 seconds.

An increase in recovery period may categorize a binder suitable for extremely traffic loading conditions. For example, at 64˚C for 1 second creep period, PMB 40 binder showed improvement in grade from '*H*' to '*E*' when recovery period was increased from 9 seconds to either 18 or 27 seconds (i.e. C1R9 changed to C1R18or C1R9 changed to C1R27). This change in grading for PMB40 shows that longer recovery period will certainly help to better evaluate rutting resistance of polymer modified binders. Likewise, CRMB 60

Table 3. Grading of Modified and Unmodified Binders as per AASHTO MP 19 for Different Traffic Loading Conditions.

Binder	T (˚C)	Grading of Binders					
		C1R9	C1R18	C1R27	C2R9	C2R18	C2R27
PMB 40	52	E	E	E	E	E	E
	64	H	E	E	H	H	H
	76	S	S	S	S^-	S^-	S^-
CRMB 60	52	E	E	E	E	E	E
	64	V	V	E	H	H	H
	76	S	S	S	S^-	S^-	S^-
VG 30	52	V	V	V	H	H	H
	64	S	S	S	S^-	S^-	S^-
	76	S^-	S^-	S^-	S^-	S^-	S^-

E = extremely high traffic loading (Traffic level ESALs< 10 million and Speed> 70 km/h)
V= very high traffic loading (Traffic level ESALs = 10-30 million or Speed 20-70 km/h)
H = high traffic loading (Traffic level ESALs > 30 million or Speed < 20 km/h)
S= standard traffic loading (Traffic level ESALs > 30 million and Speed < 20 km/h)
S- =Material is not suitable for paving purposes

binder showed improvement in grade from '*V*' to '*E*' recovery period was changed from 9 to 27 second (C1R9 changed to C1R27). However, change in recovery period from 9 second to 18 second (C1R9 changed to C1R18) didn't show improvement in grade for CRMB 60 binder. The results show that for 1 second creep period, the modified binders are showing improvement in grade when allowed to recover for longer time. However, for PMB 40 and CRMB 60, at 2 second creep period, no change in grade was observed with an increase in recovery period, indicating negligible effects of recovery period for longer creep period. Interestingly, PMB 40 binder showed same grade '*H*' when tested at 2 second creep period (C2R9) as compared to 1 second creep period (C1R9). The CRMB 60 showed reduction in grade from '*V*' to '*H*' with an increase in creep period from 1 to 2 seconds irrespective of recovery period. The unmodified binder (VG 30) showed no change in grade for increased recovery period at both creep periods. However, at 64˚C, it showed reduction in grade from '*S*' to 'S^-' for increase in creep period from 1 to 2 seconds.

At high temperature (i.e., 76˚C), PMB 40, CRMB 60 and VG 30 showed no grade change when subjected to longer recovery time under 1 and 2 second creep periods. For example, at 76˚C, PMB 40 binder showed '*S*', '*S*' and '*S*' grade for 9, 18, and 27 seconds recovery periods, similar trend were observed for CRMB 60 and VG 30. The results show that longer recovery time has no effect on grade when tested at 2 second creep period.

Summary and Conclusions

The paper evaluates effects of creep period, recovery period and temperature on rheological responses of the unmodified and modified binders. The following conclusions can be drawn from the results and discussion presented in this paper.

1. The PMB 40 binder showed increase in *R* with an increase in recovery period, except when subjected to high creep period (2 second) where effect of recovery was not noticeable. The CRMB 60 binder did not show significant increase in *R* with an increase in recovery period. The VG30 binder showed negligible *R*.
2. The *R* for both the modified binders (PMB 40 and CRMB 60) decreases with an increase in creep period from 1 second to 2 seconds, expect for PMB 40 at 52˚C, where the binder showed similar *R* for both the creep periods.
3. The plot of J_{nr} versus *R* shows that at 52˚C, CRMB 60 responded like a binder modified with elastomeric polymer, however, its behavior diminishes rapidly at higher temperature and at longer creep period. For PMB 40, majority of the points were above the standard line, indicating presence of acceptable quantity of elastomeric polymer.
4. The J_{nr} of VG 30 and CRMB 60 did not show much variation with an increase in recovery period at different creep period and temperatures. However, J_{nr} value for PMB 40 binder decreases with an increase in recovery period, except at 64˚C and 76˚C when a sample was subjected to 2 seconds creep. The results indicate that the present loading condition (C1R9) may show low rut resistant performance of a polymer modified binder.
5. Unmodified binder (VG 30) observed less stress sensitive. Modified binders observed stress sensitive with an increase in temperature, creep period, and rest periods. Except at 64˚C, the stress sensitivity of PMB 40 binder decreases with an increase in recovery period. The temperature has significant influence on stress sensitivity of a binder. The $J_{nr,diff}$ increases with an increase in temperature.
6. At 52˚C temperature, the current loading conditions (C1R9) are reasonable to capture behavior of modified and unmodified binders. However, at higher temperature, the performance of binders changes. At 64˚C temperature, increase in recovery time led to increase in adequate traffic level of PMB 40 and CRMB 60. It can be concluded that for modified binders, a longer recovery period is required at 1 second loading condition. At high temperature (76˚C), PMB 40 and CRMB 60 binders did not showed any change in gradation for longer recovery period when tested at 1 and 2 second creep period. Irrespective of temperature, the unmodified binder (VG 30) showed no change in grade for longer recovery period for both creep periods.

The conclusions presented in this paper are based on the limited number of modified and unmodified binders. Thus, it is recommended to enhance the asphalt binder database so outcome of the study could be strengthen. In addition, the asphalt binder performance at different creep and recovery periods should be correlated with field performance of a pavement.

References

1. D'Angelo, J. (2009). The relationship of the MSCR test to rutting. *Road Materials and Pavement Design*, 10, sup1, pp. 61-80.
2. Anderson, D.A. and Kennedy, T.W. (1993). Development of SHRP binder specification. *Journal of the Association of Asphalt Paving Technologies*, 62, pp.481–501.
3. Bahia, H.U., Hanson, D.I., Zeng, M., Zhai, H., Khatri, M.A., and Anderson, R.M. (2001). Characterization of modified asphalt binders in superpave mix design. NCHRP Report No. 459. Transportation Research Board, National Academy Press, Washington, D.C., USA.
4. Bouldin, M.G., Dongre, R., and D’Angelo, J. (2001). Proposed refinement of Superpave high-temperature specification parameter for performance-graded binders. *Transportation Research Record*, 1766, pp. 40–47.
5. Shenoy, A. (2001). Refinement of the Superpave specification parameter for performance grading of asphalt. *Journal of Transportation Engineering*, 127(5), pp. 357–362.
6. D’Angelo, J. and Dongre, R. (2002). Superpave binder specifications and their performance relationship to modified binders. *Proceedings of Canadian Technical Asphalt Association*, No. XLVII, pp. 91–103.
7. Tabatabaee, N. and Tabatabaee, H.A. (2010). Multiple Stress Creep and Recovery and Time Sweep Fatigue Tests. *Transportation Research Record*, 2180, pp. 67-74.
8. Wasage, T.L., Stastna, J.J., and Zanzotto, L. (2011). Rheological analysis of multi-stress creep recovery (MSCR) test. *International Journal of Pavement Engineering*. 12(6), pp. 561-568.
9. Zoorob, S.E., Castro-Gomes, J.P., Oliveira, L.A.P., and O’Connell, J. (2012). Investigating the multiple stress creep recovery bitumen characterization test. *Construction and Building Materials.* 30, pp. 734-745.
10. American Association of State Highway and Transportation Officials (2013). Standard specification for performance-graded asphalt binder, AASHTO designation: MP 19, Washington, DC, USA.
11. Delgadillo, R., Bahia, H.U., and Lakes, R. (2012). A nonlinear constitutive relationship for asphalt binders. *Materials and structures*, 45(3), pp. 457-473.
12. Domingos, M.D.I. and Faxina, A.L. (2015). Rheological analysis of asphalt binders modified with Elvaloy® terpolymer and polyphosphoric acid on the multiple stress creep and recovery test. *Materials and Structures*, 48(5), pp. 1405-1416.
13. Domingos, M.D.I. and Faxina, A.L. (2014). Creep-Recovery Behavior of Asphalt Binders Modified with SBS and PPA. *Journal of Materials in Civil Engineering*, 26(4), pp. 781-783.
14. Diab, A. and You, Z. (2014). Evaluation of Foam-based Warm Mix Asphalt Modified with Nano-sized Hydrated Lime Using Multiple Creep and Recovery Tests. *Proceedings*, *Second Transportation & Development Congress*, Orlando, FL, USA, pp. 230-238.
15. American Society for Testing and Materials. Standard Test Method for Multiple Stress Creep and Recovery (MSCR) of Asphalt Binder Using a Dynamic Shear Rheometer, ASTM designation: D 7405-10a, West Conshohocken, PA, USA.
16. D'Angelo, J., Kluttz, R., Dongre, R.N., Stephens, K., and Zanzotto, L. (2007). Revision of the Superpave High Temperature Binder Specification: The Multiple Stress Creep Recovery Test (With Discussion). *Journal of the Association of Asphalt Paving Technologists*, 76, pp. 123-162.
17. Domingos, M.D.I. and Faxina, A.L. (2015). Rheological behaviour of bitumens modified with PE and PPA at different MSCR creep–recovery times. *International Journal of Pavement Engineering*, 16(9), pp. 771-783.
18. American Association of State Highway and Transportation Officials (2013). Multiple Stress Creep Recovery (MSCR) Test of Asphalt Binder Using a Dynamic Shear Rheometer (DSR), AASHTO designation: TP 70, Washington, DC, USA.