Evaluating the Performance of Crumb Rubber Modified Binders used in Isfahan Province

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Abstract:

The performance of asphalt binders at high and low temperatures has an important role on the rutting and cracking resistance of asphalt pavements. Crumb Rubber Modified (CRM) is one of the asphalt modifiers that improves asphalt physical and mechanical properties and helps reducing environmental pollution. In this research, three unmodified and six CRM modified binders were tested using the Superpave test and Performance Grading (PG) system. The Multiple Stress Creep and Recovery (MSCR) test was used to assess rutting resistance of rubberized binders. The study compared the results of this classification with the 7 performance grade binders required for specific climatic zones in Isfahan Province. The results show that, CRM improves asphalt's physical and mechanical properties at service temperatures and decrease in the non-recoverable compliances (Jnr) in MSCR test. Moreover, CRM binder is sufficient for the required PGs, while based on MSCR test, it cannot fully cover the traffic level requirements in Isfahan Province.

Keywords: Crumb rubber, asphalt binder, traffic compatibility, MSCR test, rheological properties

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1. Introduction

Asphalt binder as a material possessing viscoelastic behavior, is considered one of the main traffic abiding components in asphalt, which plays an important role in many performance behaviors of pavement, including rutting resistance, fatigue damage and temperature cracks. Adding polymers as modifiers tend to improve pavement quality and performance and decrease damage and maintenance costs [McGennis, Anderson, Kennedy, and Solaimanian, 1994]. Nowadays, with the increased traffic loads and adverse atmospheric effects, polymer modification is a beneficial way to enhance the performance of asphalt binder resulting in reducing pavement distresses and maintenance costs [G. Airey, 2004; G. D. Airey, 2003; García-Morales, Partal, Navarro, Martínez-Boza, and Gallegos, 2004; Polacco, Stastna, Biondi, and Zanzotto, 2006]. In recent years, there has been considerable development regarding the use of recycled polymers as an alternative to pure polymers. Using recycled polymers is not only an environment-friendly approach to meet the needs, but also an appropriate way of disposing of waste. Every year, more than 40 million scrap tires are disposed of in landfills all over the country, which creates drastic environmental problems and even hazards [Ghavibazoo and Abdelrahman, 2013]. In Iran, rate of used tire production is about 7 million rings of tire which is equal to 220 tons [Shafabakhsh, Sadeghnejad and Sajed, 2014].

Crumb Rubber Modifier (CRM) was one of the first modifiers used in asphalt. Using CRM as an asphalt modifier improves asphalt's several physical and mechanical properties, including rutting resistance, ageing and fatigue resistance and thermal cracking [H. U. Bahia and Davies, 1994; Huang, 2008; Huang and Pauli, 2008]. In addition to environmental and economic advantages, using rubber bitumen results in a noticeable improvement in bitumen properties, it shows a different rheological and physical behavior [Hosseinnezhad, Holmes and Fini, 2014].

The effect of CRM on low temperature performance of asphalt and its resistance to thermal cracking has been widely studied. Some have studied the effect of CRM on low temperature performance of different asphalt binders. According to these researchers, CRM improves the stiffness of binder at low temperatures. Increasing the CRM concentration lead to substantial reduction creep stiffness of asphalt binder and consequently enhances the thermal cracking resistance [Bahia, Zhai, and Rangel, 1998; Billiter, Davison, Glover and Bullin, 1997; Ghavibazoo and Abdelrahman, 2014; Gopal, Sebaaly and Epps, 2002].

In NCHRP 9-10 project, Bahia et al. evaluated the direct correlation between a mixture's rutting properties and $|G^*|/\sin(\delta)$ on RTFO aged binders, tested at the same temperature at which the mixture test was conducted. The results indicated a poor correlation between the mixture rate of accumulated strain and the parameter $|G^*|/\sin(\delta)$.This parameter, which was found to work well for unmodified asphalts, does not give correct predictions for polymer-modified asphalts [Bahia et al. 2001].

Multiple Stress Creep and Recovery (MSCR) test a relatively new test developed by the Federal Highway Administration (FHWA) and introduced by D'Angelo et al. The test offers a simpler procedure that may hold the key to quantitatively rating modified binder for expected performance [J. D'Angelo, Kluttz, Dongre, Stephens, and Zanzotto, 2007; D'Angelo and Dongre, 2007]. This test can indicate the presence and capacity of a polymer network, thus eliminating the need for tests such as force ductility, elastic recovery and toughness and tenacity [Soenen, Blomberg, Pellinen, and Laukkanen, 2013]. Previous research has shown that Jnr correlates with the rutting performance. As measured by flow time testing, rutting resistance improves as Jnr decrease, while Superpave parameter $G^*/\sin(\delta)$ and the MSCR recovery didn't good correlate with the flow time results. Regarding rutting resistance, Jnr is a better indicator and should be considered as a simpler and more affordable alternative to elastic recovery and forced ductility testing for polymer modified binders [DuBois, Mehta and Nolan, 2014].

In this study, a laboratory evaluation of the relative performance of CRM binder in terms of PG and MSCR tests and classification with the CRM bitumen required for specific climatic zones and traffic level in Isfahan Province of Iran has been presented. A list of the required performance graded binders derived from a PG climate study conducted for Isfahan Province is presented in Table 1.

Table 1. Required PG grades in Isfahan Province [Goli, 2007]

City	LT (°C)	IT (°C)	HT (°C)	PG grade
Abyaneh	-16	25	58	**PG 58-16**
Daran	-22	22	58	**PG 58-22**
Badijan	-28	19	58	**PG 58-28**
Isfahan	-16	28	64	
East of Isfahan	-16	28	64	
Isfahan of Refinery	-16	28	64	
Kabootarabad	-16	28	64	**PG 64-16**
Shahreza	-16	28	64	
Natanz	-16	28	64	
Nain	-16	28	64	
Meymeh	-22	25	64	
Golpayegan	-22	25	64	**PG 64-22**
Hamgin	-22	25	64	
Damaneh	-28	22	64	
Chadegan	-28	22	64	**PG 64-28**
Singerd	-28	22	64	
Khoor	-10	34	70	
Ardestan	-10	34	70	**PG 70-10**
Kashan	-10	34	70	

2. Materials and Methods

2.1 Materials

CRM used in this study produced by mechanical shredding at ambient temperature and was obtained from one source of -14 mesh (1.410 mm) and used with a gradation as shown in Figure 1. Rubberized binder samples were made by blending CRM and three base binder at two percentages of CRM (10% and 15%) by the weight of the total binder. The properties of base binder is shown in Table 2. CRM was added when the base binder reached 150 °C and blended for 15 minutes at low shear using a mechanical mixer. After CRM was added completely, the temperature was stabilized at 190 ºC and blending continued using a Silverson L5RT high-shear mixer with 120 min at 4000 rpm. Rubberize binder code, binder type and the amount of CRM by mass binder are represented in Table 3.

2.2 Experimental Test Methods.

In order to study the properties of binders (unmodified and modified with CRM), we conducted rotational viscosity (RV), dynamic shear rheometer (DSR), and blending beam rheometer (BBR) tests based on the Superpave performance grading specification [ASTM-D6373, 1999].

The rotational viscosity test was to assure bitumen pumping and bitumen mixing with hot aggregates. According to ASTM D4402 recommendations, bitumen viscosity should be less than 3 Pa.s at 135 °C.

The dynamic shear rheometer test was conducted at the frequency of 10 rad/s (1.6 Hz) and at the required high and medium temperatures to control high and medium temperatures respectively. The properties of asphalt binders (unmodified and modified with CRM) were evaluated following AASHTO T 315 standard. Short-term aging of the binders was achieved using the rolling thin-film oven (RTFO) aging procedure to simulate aging during construction according to AASHTO T 240. Long-term aging, which simulated field aging during the first 7 to 10 years of service life, was achieved by using the Pressure Aging Vessel (PAV) procedure according to AASHTO R 28.

The Bending Beam Rheometer (BBR) test was conducted to evaluate rheological properties of binders at low temperatures in accordance to Superpave specification. The creep stiffness, S, and the relaxation rate parameter, m-value, were determined over 240 s of creep loading for the tested asphalt binders. This test was carried out according to the AASHTO T 313 specification using PAV-aged binder residue at -12,-18 and –24 °C.

The MSCR tests [ASTM-D6373, 1999] were performed on the same DSR used in the Superpave tests.

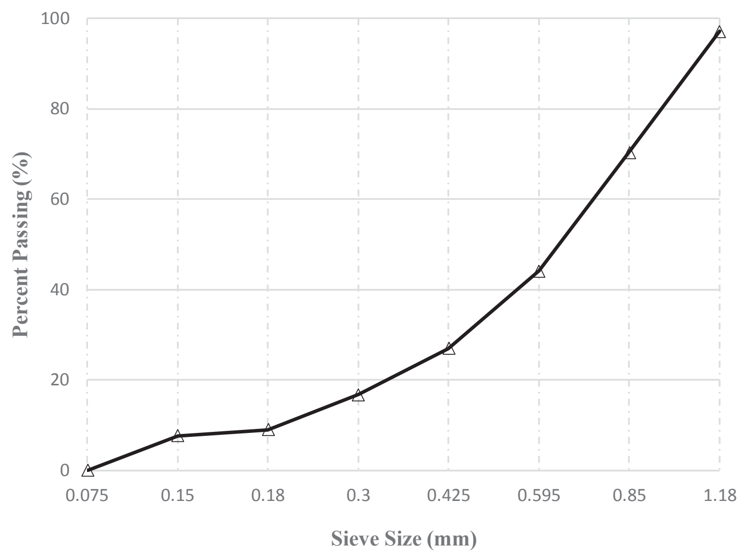

Figure 1. Gradation of CRM used in this study.

Table 2. Properties of Base Binders.

Aging states	Test properties	Test Result		
		Binder Type		
		A	B	C
Unaged binder	Flash Point Temperature (°C)	325	332	334
	Penetration @ 25 °C (0.1 mm)	190	94	66
	Softening Point (°C)	38.9	45.3	49.4
	Viscosity @ 135 °C (Pa.s)	0.162	0.317	0.322
	G*/Sin(δ) @ 52 °C (kPa)	1.39	-	-
	G*/Sin(δ) @ 58 °C (kPa)	0.59	1.59	-
	G*/Sin(δ) @ 64 °C (kPa)	-	0.66	1.05
	G*/Sin(δ) @ 70 °C (kPa)	-	-	0.47
RTFO aged residual	G*/Sin(δ) @ 52 °C (kPa)	2.62	-	-
	G*/Sin(δ) @ 58 °C (kPa)	1.09	3.73	-
	G*/Sin(δ) @ 64 °C (kPa)	-	1.53	2.84
	G*/Sin(δ) @ 70 °C (kPa)	-	-	1.07
RTFO + PAV aged residual	S-value @ -12 °C (MPa)	88.65	100.73	177.08
	S-value @ -18 °C (MPa)	258.3	227.83	345.53
	m-value @ -12 °C	0.371	0.326	0.302
	m-value @ -18 °C	0.285	0.278	0.253

Table 3. Binder codes and composition.

Binders Code	Binder Type	CRM content (percentage by mass)
Binder A	A	-
A+10% CRM	A	10
A+15% CRM	A	15
Binder B	B	-
B+10% CRM	B	10
B+15% CRM	B	15
Binder C	C	-
C+10% CRM	C	10
C+15% CRM	C	15

Samples with a diameter of 25 mm and a gap height of 1 mm were subjected to standardized loading–unloading conditions 1-s creep time, 9-s recovery time, 10 creep–recovery cycles and stress levels of 0.1 and 3.2 kPa. Finally the averages of the results of two replicates (R and Jnr) were calculated for each formulation. Table 4 shows the acceptable non-recoverable creep compliance at 3.2 kPa and difference percentages for various levels of traffic as specified in ASSHTO T350.

3. Results and Discussion.

3.1 Effect of CRM on Binder Rheological Properties

In this section, the effect of CRM on binder performance grade has been evaluated. According to ASTM D2872 recommendations for managing high temperature properties of asphalt binder, the G*/Sin(δ) at high temperature (HT) for unaged bitumen and residue aged bitumen after RTFO test should be more than 1 kPa and 2.2 kPa, respectively [ASTM-D2872, 1997]. In addition, for control of low temperatures properties of asphalt binder, low temperature (LT) is 10 °C lower than the temperature at which the PAV [ASTM-D6521, 2003] aged binder exhibits creep stiffness of less than 300 MPa and m-value of greater than 0.30 at 60 s of loading [ASTM-D6648, 2001].

Figure 2 shows the effect of added CRM on HT performance of binder based on Superpave tests. According to Figure 2, the addition of CRM and an increase in the amount of CRM, significantly increase the HT performance of the CRM modified binder. Increasing the CRM content significantly increases the absorption of light molecular weight components of binder which may have effect on the HT performance of the CRM modified binders.

Figure 3 represents the intermediate temperature fatigue parameter (G*× Sin (δ)) of CRM modified binder after PAV test. In order to resist fatigue cracking, the binder should be elastic but not too stiff and an im-

Table 4. Acceptable non-recoverable creep compliance.

Jnr,3.2Kpa-1 (AASHTO T315)	Grade	Traffic Designation
≤ 4.5	Standard (S)	< 10 million ESAL
≤ 2.00	Heavy (H)	10 - 30 million ESAL
≤ 1.00	Very Heavy (V)	> 30 million ESAL
≤ 0.5	Extreme (E)	> 30 million ESAL and standing traffic

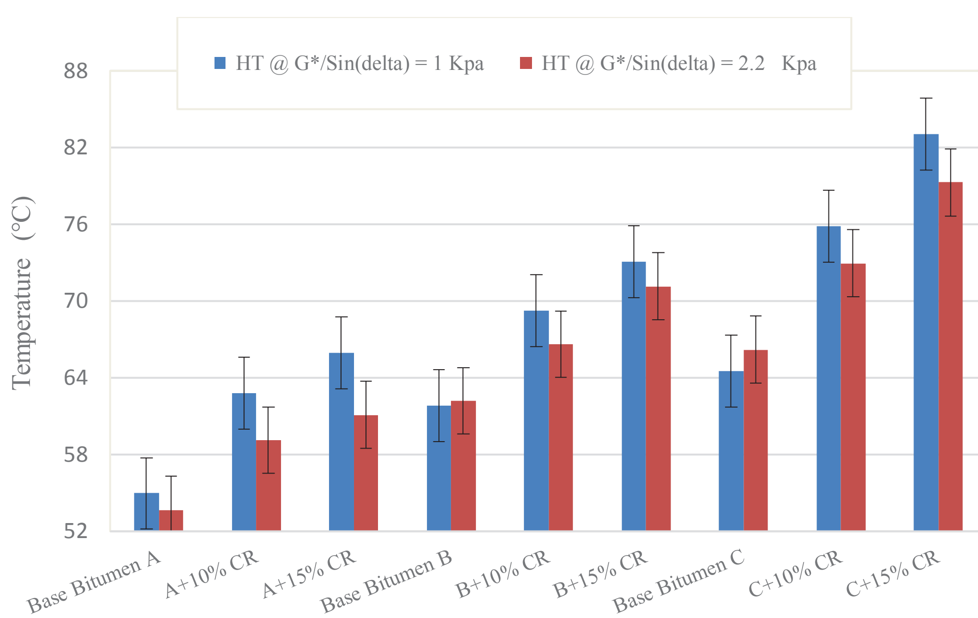

Figure 2. Effect of CRM content on High-temperature parameter before and after RTFO test.

provement to be a decrease in temperature at which the limiting stiffness. Figure 3 represents the effect of CRM on the function of intermediate temperature (IT) in binder modifiers. The IT on unmodified and modified bitumen indicated that CRM causes a decrease in IT of unmodified binder in that the more the amount of CRM, the more the IT of the modified bitumen. Increasing the CRM content significantly increases the absorption of light molecular weight components of asphalt binder which may have influence on the fatigue behavior of the CRM modified binders.

Table 5 presents the effect of CRM on intermediate temperature performance on the rubberized binder. Based on the resulted in Table 5, can be seen that CRM have decreased the IT and improved the fatigue resistance. The main reason for decrease in IT of asphalt binder after addition of CRM may be the increase in complex modulus and the decrease in phase angle.

Figure 4 shows the results of the bending beam rheometer test base stiffness and m-value of the CRM binder at different temperatures. The LT of unmodified and modified bitumen indicated that adding CRM improves LT of unmodified bitumen, and the more the amount of CRM, the more the LT of modified bitumen. Based on the results, the samples with the higher CRM concentration (15%) have better performance than the one with the lower CRM concentration.

Figure (5) demonstrates that rotational viscosity for rubberized binders with different temperature. According to the results of the viscosity test, CRM caused an increase in viscosity of unmodified bitumen in that the more the content of CRM, the more the viscosity of modified bitumen. This can be attributed to the gradual CRM caused by the release of dissolution part of polymer from CRM to asphalt binder. With respect to the viscosity test results, it is evident that the viscosity of all modified bitumen samples are less than 3 Pa.s and, satisfying the ASTM D6373 criterion for asphalt binder workability.

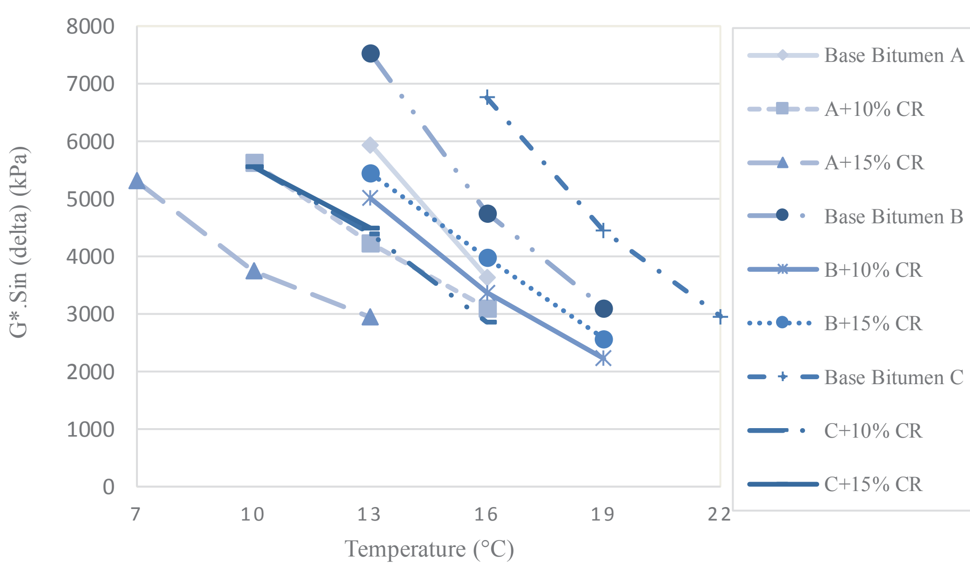

Figure 3. Effect of CRM content intermediate -temperature before and after RTFO test.

Table 5. Effect of CRM on intermediate temperature performance.

Bitumen Code	G*.Sin(δ) @ 5000 (KPa)	IT improvement (°C)
Base Bitumen A	14.23	-
A+10% CRM	11.35	2.88
A+15% CRM	7.61	6.62
Base Bitumen B	15.74	-
B+10% CRM	13.03	2.71
B+15% CRM	13.92	1.82
Base Bitumen C	18.29	-
C+10% CRM	11.44	6.85
C+15% CRM	11.88	6.41

(6)

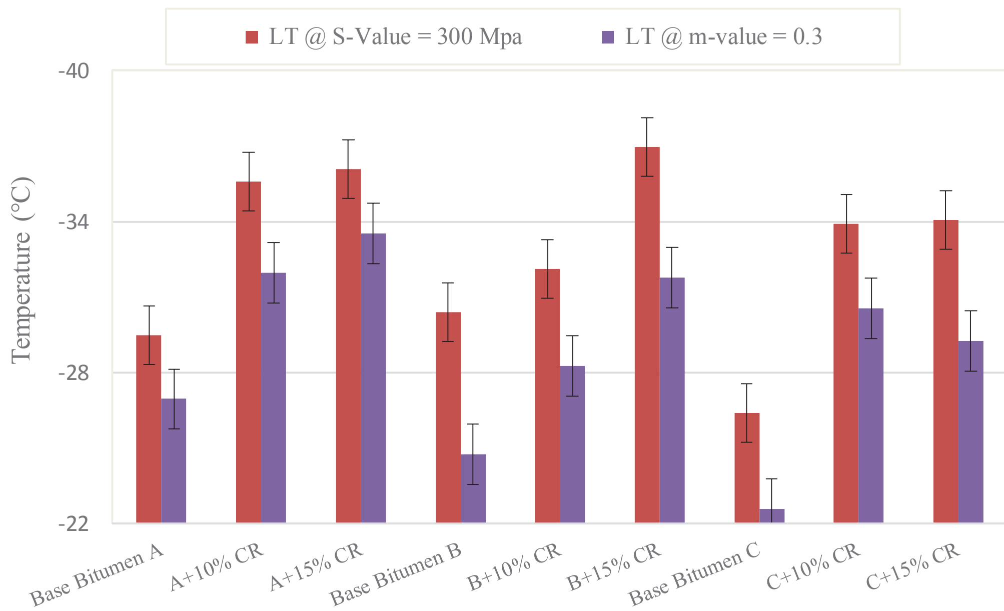

Figure 4. Effect of CRM on Low-temperature performance.

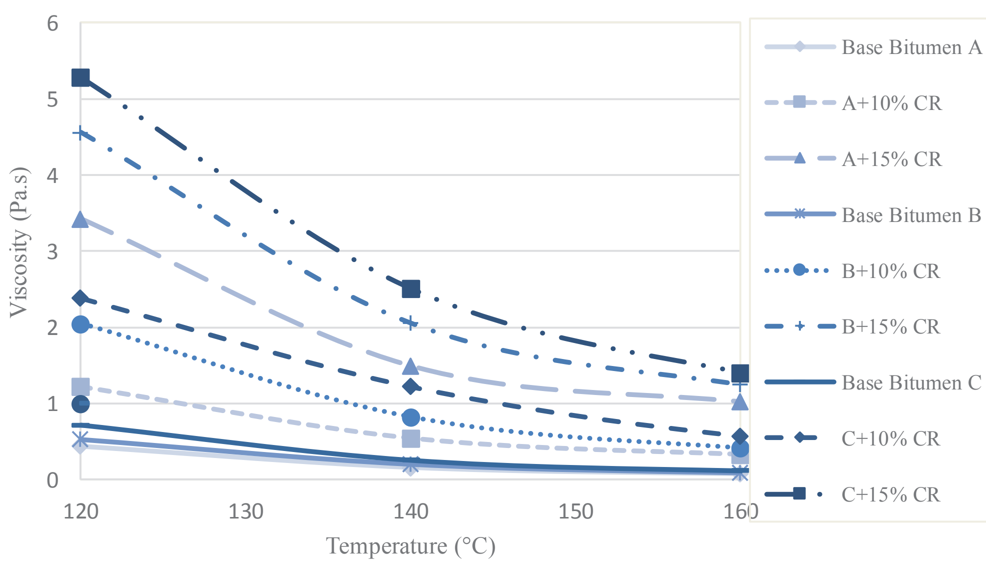

Figure 5. Dynamic viscosity curves of modified bitumen.

3. Effect of CRM on Performance Grade

Table 6 shows the results for the effect of CRM as an additive on HT and LT of the bitumen, the amount of HT and LT improvement for each modified bitumen in comparison with the base bitumen, performance temperature range (HT–LT), and performance range expansion compared with the base bitumen. According to performance grades of modified bitumen based on Superpave PG system, it can be concluded that adding CRM to unmodified bitumen led to improve high and low temperature performance of the unmodified bitumen. According to Table 8, C+15% CRM denotes the largest performance range expansion, resulting in about 28 °C expansion. In addition, bitumen C+10% CRM, C+15% CRM, and B+15% CRM show a service temperature range beyond 100 °C.

Table 6 shows the present unmodified and modified bitumen with the 7 required grades based on climatic zones in Isfahan Province. The existing neat bitumen samples received only four out of seven required performance grades (58-16, 58-22, 64-16 and 64-22). The other three PGs (58-28, 64-28 and 70-10) were not available although required. In other word, neat bitumen samples did not cover Daran, Damaneh, Chadegan, Singerd, Khoor, Ardestan and Kashan cities. According to the results represented in Table 7, it can be observed that CRM binders are capable of covering all climatic zones in Isfahan Province.

3.3 Effect of CRM on Rutting Performance

MSCR test was also conducted for base and GTR modified binders to investigate rutting resistance of these materials. The Jnr is presently being considered as the most appropriate rheological parameter for assessing the propensity of an asphalt binder to resist permanent deformation or rutting in the pavement wheel paths [Shenoy, 2008].

Figs. 6 and 7, illustrates Jnr of the asphalt binders. The presence of CRM decreased Jnr values, especially at high temperatures and high stress levels. Due to the fact that Jnr is an indicator of the susceptibility of the asphalt binder to rutting, it can be stated that CRM modified bitumen is less prone to the accumulation of unrecovered strain under creep and recovery loading, compared with unmodified bitumen. Considering only the rheological properties of the asphalt binder, the lowest rutting levels may be obtained when the CRM modified binder is used in the asphalt mixture. Lower Jnr values indicate that the material is less susceptible to the accumulation of plastic deformation. Basically, this indicates that adding the CRM leads to a release of the polymeric components with higher molecular weights into the asphalt matrix and consequently enhances the rutting resistance of the CRM modified binder [Zanzotto and Kennepohl, 1996].

Table 8 shows the present unmodified and modified bitumen within the 7 classifications based on climatic zones and traffic level in Isfahan Province. The existing neat bitumen B and C samples covered only the standard traffic level (S) at 58 °C and 64 °C, respectively. In other hand, neat bitumen is less than 10 million ESAL, while other required traffic designation but not available. According to table 8, crumb rubber modified bitumen are capable to cover all climatic zones and traffic level standards, including those of heavy traffic, in Isfahan Province while CRM binders only covered less than 30 million ESAL traffic for Khoor, Ardestan and Kashan cities. According to the results of the following table, the traditional system (performance grading) is clearly incapable of grading of bitumen (rutting resistance). In the traditional system, passing traffic volume is not taken into consideration, resulting in increased

Table 6. Modified asphalt binders service temperature.

Sample Code	HT (°C)	LT (°C)	HT improvement (°C)	LT improvement (°C)	Performance grade
Base Bitumen A	53.64	-26.95	-	-	52-22
A+10% CRM	59.09	-31.97	5.45	5.02	58-28
A+15% CRM	61.08	-33.54	7.44	6.59	58-28
Base Bitumen B	61.80	-24.75	-	-	58-22
B+10% CRM	66.62	-28.27	4.82	3.52	64-28
B+15% CRM	71.13	-31.78	9.33	7.03	70-28
Base Bitumen C	64.52	-22.6	-	-	64-22
C+10% CRM	72.92	-30.56	8.4	7.96	70-28
C+15% CRM	79.25	-29.27	14.73	6.67	76-28

Table 7. Classification of modified asphalt binders based on climatic zones in Isfahan Province.

Required PG grade	City	Binder A	A+10 % CR	A+15 % CR	Binder B	B+10 % CR	B+15 % CR	Binder C	C+10 % CR	C+15 %CR
58-16	Abyaneh		OK.	OK.	OK.	OK.	OK.	OK.	OK.	OK.
58-22	Daran		OK.	OK.	OK.	OK.	OK.	OK.	OK.	OK.
58-28	Badijan		OK.	OK.		OK.	OK.		OK.	OK.
64-16	Isfahan- Kabootarabad- Shahreza- Natanz- Nain- Isfahan of Refinery					OK.	OK.	OK.	OK.	OK.
64-22	Meymeh- Golpayegan- Hamgin					OK.	OK.	OK.	OK.	OK.
64-28	Damaneh- Chadegan- Singerd					OK.	OK.		OK.	OK.
70-10	Khoor- Ardestan- Kashan						OK.		OK.	OK.

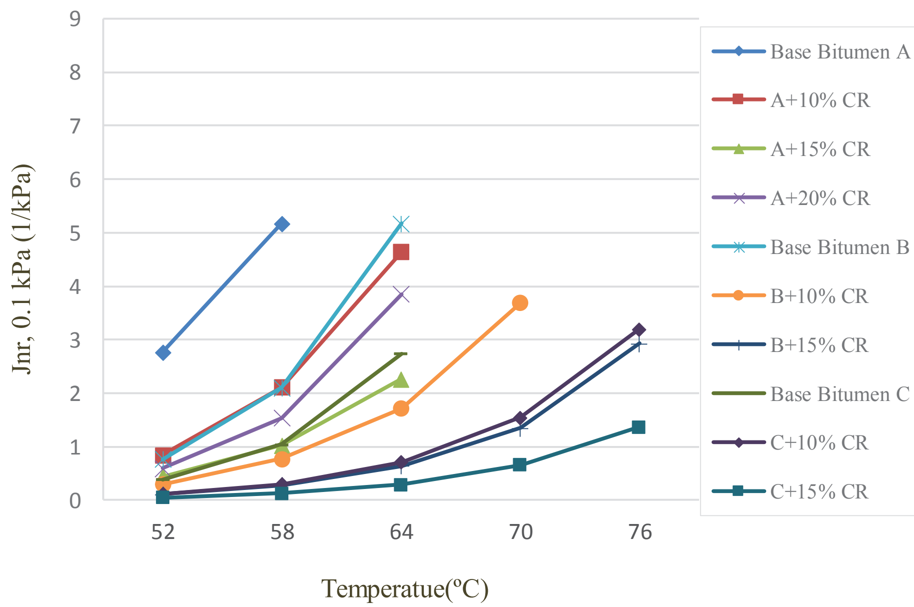

Figure 6. Nonrecoverable compliances at 0.1 kPa of asphalt binders.

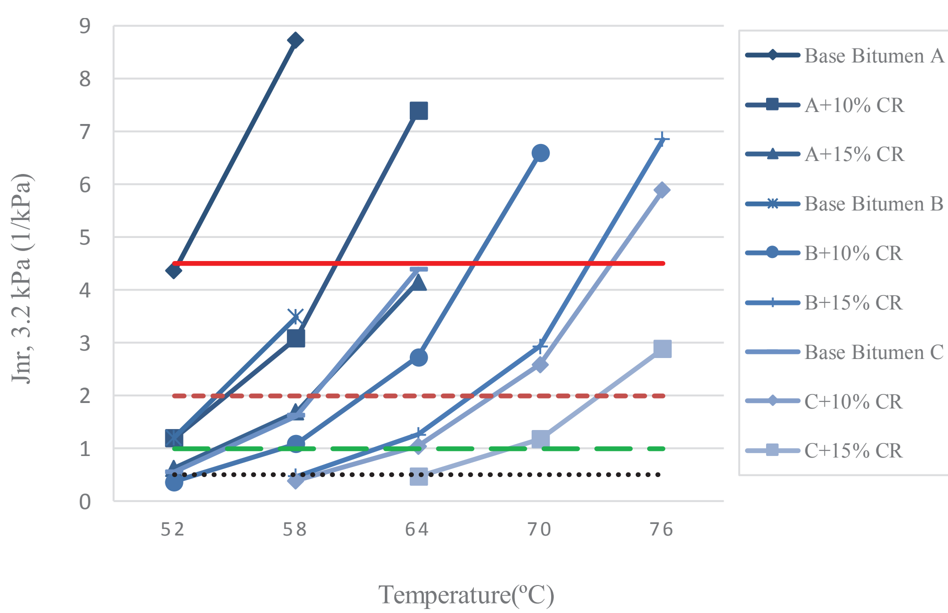

Figure 7. Nonrecoverable compliances at 3.2 kPa of asphalt binders.

failure rate in surfacing (rutting in high temperatures). On the other hand, in the new system (with PG) traffic conditions are taken into account, which results in a more precise grading of bitumen. For example, according to the table below, in traditional systems, bitumen C+15% CRM is considered suitable for PG 70-10, while in new systems, in which traffic criteria are included, this bitumen is only considered suitable for standard and heavy traffic conditions in Khoor, Ardestan and Kashan cities.

4. Conclusion

This study was focused on the performance properties of rubberized binders as a function of CRM content and base binder. Superpave and MSCR tests were conducted. In addition, the performance of CRM binders used in Isfahan Province was evaluated. According to the laboratory tests and the required standards for Isfahan Province, the following can be concluded:

- The result of Superpave test indicated that adding CRM improved high and low temperature performance

Table 8. Classification of modified asphalt binders based on climatic zones and traffic levels in Isfahan Province.

Required PG grade	City	Binder A	A+10 % CR	A+15 % CR	Binder B	B+10 % CR	B+15 % CR	Binder C	C+10 % CR	C+15 % CR
58-16	Abyaneh		S	H	S	H	E	H	E	E
58-22	Daran		S	H	S	H	E	H	E	E
58-28	Badijan		S	H		H	E		E	E
64-16	Isfahan-Kabootarabad-Shahreza-Natanz- Nain- Isfahan of Refinery			S		S	H	S	H	E
64-22	Meymeh- Golpayegan- Hamgin			S		S	H	S	H	E
64-28	Damaneh- Chadegan- Singerd			S		S	H		H	E
70-10	Khoor- Ardestan- Kashan						S		S	H

of asphalt binders.

- The evaluation of Superpave test results shows that improvement service temperatures of the CRM modified binder, depend on the type of base bitumen. For HT the best choice would be bitumen C (Pen 60-70) and for LT the best choice would be bitumen containing vacuum bottom.
- The addition of CRM lead to a decrease in permanent deformations, hence improving rut resistance of the asphalt binder. In addition, CRM modified binders show better fatigue behavior compare to the base binder.
- Investigation the performance of CRM binders used in Isfahan Province shows that the existing neat binder samples covered only four out of seven required performance grades; however, CRM binder is adequate to fully cover the required PGs in Isfahan Province, while it does not fully satisfy the traffic level requirements.

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