[Baha *, 5(7): July, 2018]
DOI: 10.5281/zenodo.1310909
ISSN 2349-6193
Impact Factor: 3.866

IJESMR

International Journal OF Engineering Sciences & Management Research

EFFECTS OF EVOTHERM ON CONVENTIONAL AND RHEOLOGICAL PROPERTIES OF CRUMB RUBBER MODIFIED BINDER

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Keywords: *Evotherm, Crumb Rubber, Conventional Properties, Rheological Properties*.

ABSTRACT
The combined usage of additive in the same binder is a new research area among the highway engineers. In this study the rheological and conventional properties of binders produced with crumb rubber (CR) and Evotherm which is a warm-mix additive were evaluated and compared with the neat bitumen. The binders were prepared in 8 different combinations. CR and Evotherm contents were kept constant at 10% and 0.7% by weight of neat bitumen, respectively. Penetration, softening point, rotational viscometer (RV), dynamic shear rheometer (DSR) and bending beam rheometer (BBR) test were conducted to base and modified binders. In conclusion it was determined that use of CR individually induces an increase in viscosity, softening point and complex modulus with the increase of additive content. It also contributes to low temperature performance by providing low stiffness and high m-value. On the other hand the use of Evotherm both individually and with CR modification do not induce positive or negative variation in performance of binder in terms of conventional and rheological tests. However it can provide just a bit benefit on flexible behavior of CR modified binder by offering lower phase angles in DSR test.

INTRODUCTION
The number of waste tires has been increasing with the increase of population by inducing environmental pollution and fire hazards. Due to the inclusion of waste tires high content of rubber which is a very precious material, its use in bituminous mixtures provides a cost effective solution and environmental protection. While crumb rubber (CR) modification ensures an improvement on the mixtures'properties, it also gives an unfavorable workability properties due to increased viscosity[1-3]. The studies concluded that CR modification improved the performance of pavement, life cycle cost and the environmental benefits [4-7]. Kaloush et al. determined that CR modification can increase the degree of the high temperature grade of bitumen and also improves the viscosity and temperature susceptibility [8]. However, crumb rubber modified asphalts (CRMA) induce high mixing-compaction temperature thus higher energy consumption and environmental contamination during the production processes compared to unmodified mixtures [9]. In order to mitigate this negativity, warm-mix-additives which are induced a reduction in viscosity are used. The CR modified mixtures with warm-mix additives can be produced 20-40°C lower temperature than only CR modified mixtures [10]. Using warm-mix additives such as Sasobit and Rediset reduce the temperature susceptibility and improve the rutting parameter of styrene-butadiene-styrene (SBS) modified binders [11]. Warm-mix additives such as Cecabase, Sasobit, Evotherm and Rediset are reported to induce a reduction in viscosity of neat bitumen and so in mixing-compaction temperatures [12]. Sasobit gives higher rutting parameter and lower phase angle compared to other warm-mix additives [12-13]. Evotherm M1 which is a chemical additive is used as surface active material and it provides 30-40°C lower mixing-compaction temperature than hot mixtures [14]. A road construction project was successfully applied by using Evotherm at low weather temperature in China [15]. In this study it was denoted that the residual water (< 0.05%) in the Evotherm reduces the viscosity of the binder during the compaction and enables a good compaction at 80-140°C. Ghabchi et al. concluded that Evotherm modification increases the adhesion properties which is more pronounced at limestone aggregate and provides more wettability properties than that of the neat bitumen [16]. It was concluded that although warm mix additive induce a reduction in production temperature of crumb rubber modified mixtures, they have different influences on rheological properties of these mixtures [17].

Few researchers have handled to utilize different additives in the same binder until now. In this study the rheological and conventional properties of binders including crumb rubber and Evotherm were evaluated. The study aims to determine how the binder properties are affected by the common usage of these additives and compare with the neat bitumen.

 ISSN 2349-6193
Impact Factor: 3.866

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MATERIALS AND METHODS

In this study, B 50/70 bitumen provided by Kırıkkale refinery in Turkey was used as base binder. The basic characteristics of base binder are given in Table 1. The crumb rubber grounded with mechanic chop method into 0.3-0.6 mm dimensions was supplied from Samsun Waste Plastic company. Another additive used as warm-mix-additive in the experiment is Evotherm supplied by MeadWestvaco. CR and Evotherm contents were kept constant at 10% and 0.7% by weight of bitumen, respectively. A laboratory-scale mixing device was used to prepare the modified binders. The selected mixing temperature, mixing time and mixing rate were 180°C, one hour and 1,000 rpm. respectively. In the study base and 7 modified binder given in Table 2 were evaluated. The separately and together usage of additives in the binder were evaluated by conventional (softening point, penetration) and rheological (rotational viscosity (RV), dynamic shear rheometer (DSR), bending beam rheometer (BBR)) tests.

Table 1: Properties of neat bitumen.

Properties	Value
Softening point (°C)	49.4
Penetration (0.1mm)	53.9
Penetration index	-1.20
Viscosity at 135°C (cP)	437.5
Viscosity at 165°C (cP)	137.5

Table 2: Binder combinations.

Additives	Binder types							
CR (%)	0	6	8	10	0	6	8	10
Evotherm (%)	0	0	0	0	0.7	0.7	0.7	0.7
Symbol	0-0	6-0	8-0	10-0	0-7	6-7	8-7	10-7

CONVENTIONAL TESTS

The softening point is the temperature at which the bituminous binders have an equal viscosity.In the determination of softening point,a standard ball passes through a sample of bitumen in a mold and falls through a height of 2.5 cm. It ismeasured using the ring and ball test in conformity with ASTM D36 [18]. The binders which have different softening point values will have the same consistency at their softening point. The mixture including higher softening point ensuresthat they will not flow during serviceat high temperature. The penetration grades of the binders were also measured using the penetrometer in conformity with ASTM D5 [19]. The penetration grade is widely used for the classification of bitumen. All bituminous binders exhibit thermoplastic properties. They become softer when heated and harden when cooled.This property is known as temperature susceptibility which is one of the binder's most significant characteristic. The temperature susceptibility is usually assessed by the penetration index calculated by softening point and penetration grade. Penetration Index (PI) gives a quantitative value of the behavior of bitumen to variation in temperature. The value of PI ranges from -3 for high temperature susceptible binders to +7 for low temperature susceptible bitumen.

Asphalt binders must have a sufficient fluidityin order to consume an optimal energy during the hot mixture production, laydown, and compaction processes. The rotational viscometer enables well to compare the efficiency of additives on fluidityproperties of binders. The mixing-compaction temperatures can also be determined by the viscosities at 135°C and 165°C according to AASHTO T316 [20]. The temperatures at the 170±20 cP and 280±30cPviscosity values are determined as mixing and compaction temperatures, respectively.

RHEOLOGICAL TESTS

The dynamic shear rheometer (DSR) is used to determine the viscous and elastic component of asphalt binders at medium to high temperatures. At the DSR test the complex modulus (G*) and phase angles (δ) of the asphalt binder, placed between two circular plates lower one of which is stable and upper one oscillates, are determined. High temperature performance grade is evaluated by limiting the G*/sinδ to the values greater than 1.0 kPa (before aging) and 2.2 kPa (after rolling thin film oven (RTFO) aging). The binders desired to have higher G*/sin δ value to well resist to permanent deformations at high temperatures [21]. In this study, DSR tests were carried out by Bohlin DSRII rheometer at the controlled-stress conditions and the oscillation frequency was 10

ISSN 2349-6193
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rad/s. Five test temperature including 52°C, 58°C, 64°C, 70°C and 76°C were selected. The asphalt binder samples were sandwiched using 25 mm diameter plate, and 1 mm gap.

The mixing-compaction temperatures of modified binders can also be determined at DSR test by measuring the viscosities of binders. Since there is no significant changes in viscosities after 500 Pa stress level, the test performs at 500 Pa constant stress level [22]. The asphalt binder samples were sandwiched using 25 mm diameter plate, and 0.5 mm gap opening in this procedure. The test was conducted at 76, 82 and 88°C and the temperatures corresponding to bitumen viscosities 0.17 ± 0.02 Pa.s and 0.35 ± 0.03 Pa.swere chosen as mixing and compaction temperatures respectively.

Bending Beam Rheometer (BBR) test enables to measure the low temperature stiffness and relaxation properties of bituminous binders.The test uses the three-point beam system to determine the stiffness of asphalt beam sample. Creep stiffness (S_t), is calculated based on measured deflection under a fixed static load (980 ± 50 mN). This loading is associated with the stresses that gradually developed in a pavement when temperature drops. The change in stiffness with time is also important issue. The m-value which is a measure of the rate where the asphalt binder relieves stress through plastic flow is another parameter determined from BBR test.These parameters explain the capability of an asphalt binder to resist low temperature cracking. The creep stiffness of the binders at any time of loading (*t*) is calculated by:

$$S_t = PL^3/(4bh^3\delta_t) \qquad (1)$$

where, S_t is creep stiffness (MPa) at time t, P is applied constant load (N), L is span length of beam sample (102 mm), b is beam width (12.7 mm), h is beam thickness (6.35 mm) and δ_t is deflection (mm) at time, t.

Due to the low S_t and high m-value is expected for an improved low temperature behavior, the calculation of S_t/ m-value ratio (λ) will be quite rational for assessing the crack resistance [23]. The smaller its value, the better resistance to low temperature is. In this study, the test was conducted at –15°C according to AASHTO T313 [24].

CONVENTIONAL BINDER TEST RESULTS

The changes in penetration values are given in Fig. 1 in descending order. Both CR and Evotherm induce a reduction in penetrations. CR modification is more effective in the penetration values than the Evotherm additive. Evotherm slightly contributes to this reduction when used together with CR 10% CR with 0.7% Evotherm (10-7) gives the lowest value by providing a harder bitumen compared to neat one. While penetration values of base binder reduces 33% with the use of 10% CR, it reaches to 37% when used together with 0.7% Evotherm.

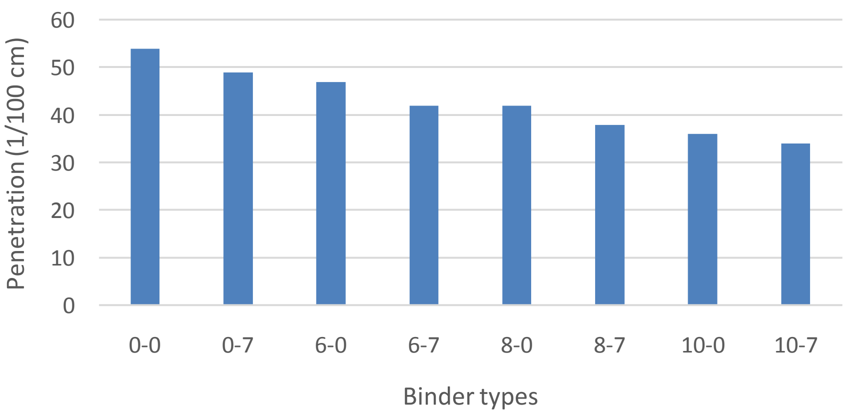

Fig 1: The variation on penetration values of binders

The changes is softening points of binder are given in Fig. 2 in ascending order. Similar behavior with the penetration test is seen here again. CR modification is more effective on increase of the softening points than the Evotherm modification. 0.7% Evotherm does not alter the softening point of the binder modified with any content of CR. The highest softening point value was obtained for the 10-7 binder which is 12.5% greater than

ISSN 2349-6193
Impact Factor: 3.866

that of the neat bitumen. In the light of these results it was determined that the usage of Evotherm with CR does not provide an improvement with respect to high temperature performance on the other hand it cannot be assumed that it has a negative influence on softening point.

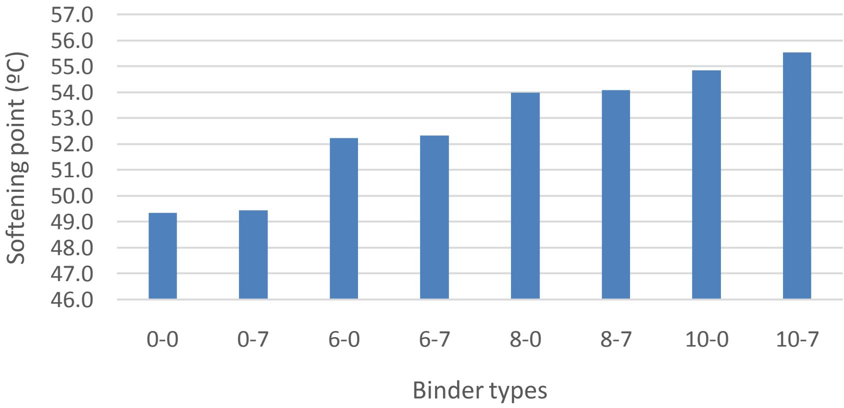

Fig 2: The variation on softening point of binders.

The variation on penetration index (PI) versus additive content are given in Fig. 3. While the individual usage of CR improved the PI values of neat bitumen, the individual usage of Evotherm slightly worsened it. Evotherm has a contribution to PI values of CR modified binder when used only with 10% CR. The usage of CR with Evotherm delivered a resanable performance in terms of temperature susceptibility providing PI values between -2 and +2.

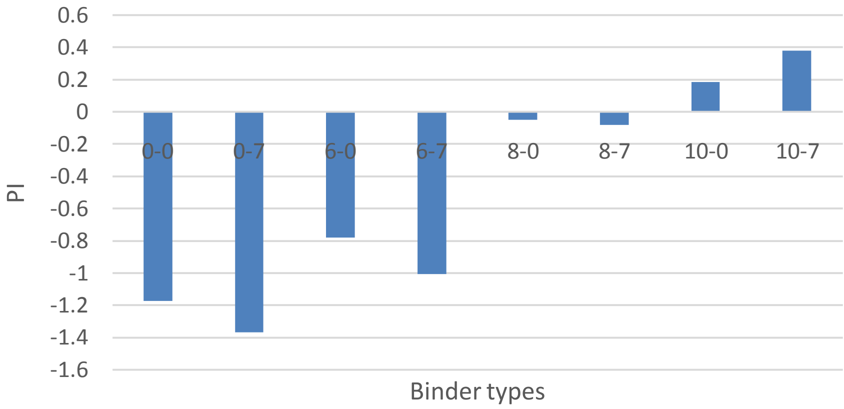

Fig 3: The variation on penetration-index of binders

The obtained viscosity and determined mixing-compaction temperatures according to 170±20 mPa.s and 280±30 mPa.s viscosity vales are given in Table 3. The variation of viscosities are also given in Fig.4. It is seen that the individual usage of CR has a significant effect on viscosity. The viscosity values of the CR modified binder increase with the increase of CR content. 6%, 8% and 10% CR induces 1.91, 2.37 and 3.09 times higher viscosity compared to neat bitumen. Both the individual and common usage of Evotherm with CR has minimum effects on reducing the viscosity. With this context Evotherm cannot provide a mixture which can be mixed and compacted at lower temperature than that of the neat or CR modified mixture. Although Evotherm is a warm-mix additive inducing a reduction in mixing-compaction temperatures as it stated in the literature which used mixture tests, this type of binder test cannot shows the efficiency of Evotherm on reduction of mixture's mixing-compaction temperatures.

Table 3: The values of viscosity and mixing-compaction temperatures.

Binder types	Viscosity (cP)		Temperature (˚C)	
	135 (˚C)	165 (˚C)	Mixing	Compaction
0-0	437.5	137.5	158.7	145.6
0-7	412.5	125.0	156.6	144.0
6-0	837.5	250.0	176.6	162.5
6-7	812.5	237.5	178.3	163.2
8-0	1030.0	325.0	184.0	168.8
8-7	1050.0	375.0	192.7	174.8
10-0	1350.0	462.5	198.6	180.9
10-7	1325.0	462.5	198.6	180.6

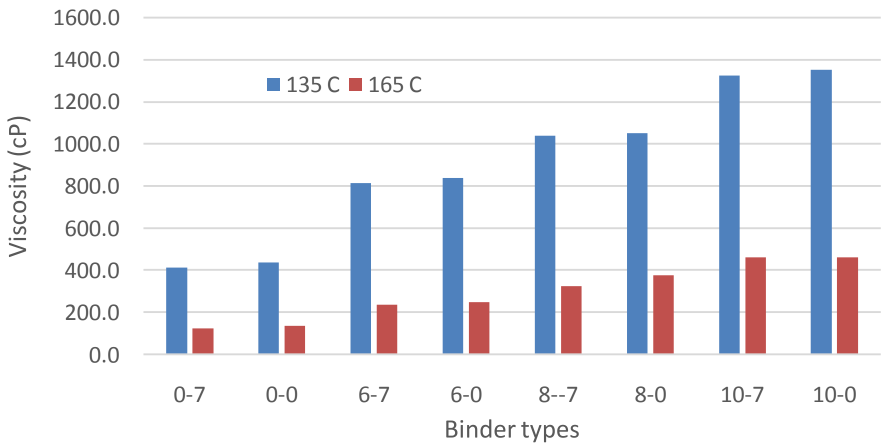

Fig4:The variation on viscosities of binders

RHEOLOGICAL BINDER TEST RESULTS

DSR results at 10 rad/s frequency and at different temperatures are presented in Table 4. It was determined that G*/sinδ values of all binders decreased to half with the increase of every 6 degrees. The changes of G*/sinδ values with temperature are given in Fig. 5. Rutting parameter of all binders decrese with the increse of temperature. Moreover rutting parameters are getting closer to each other and the binder types comes down with the increse of temperature. The most differences among the rutting paremeter of the binder occurs at low temperatures 0-7 and neat bitumen give the lowest values, 10-0 and 10-7 binders give the highest values.

Table 4: G/sinδ values of the binders.*

Binder types	Temperature (°C)				
	52	58	64	70	76
0-0	7538	3230	1430	675	
0-7	7138	3067	1337	647	
6-0	11948	5363	2403	1188	
6-7	12022	5408	2515	1229	
8-0	14594	6511	3076	1511	
8-7	14330	6715	3151	1531	801,5
10-0	18378	8714	4098	2010	1025
10-7	17899	8324	3848	1910	1000

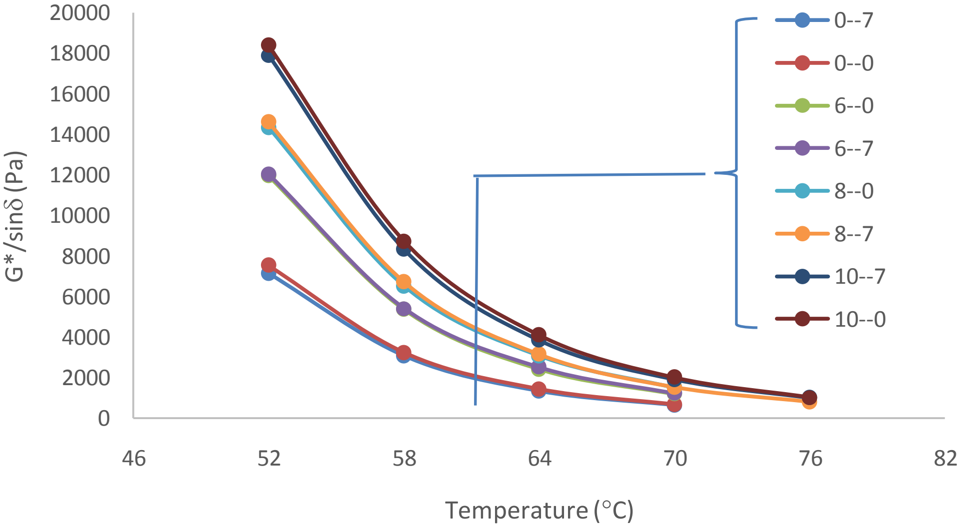

Fig 5: The variation on rutting parameters versus temperature.

The variation on G*/sinδ values and phase angles at 52ºC where the differences are high are given in Fig.6 and Fig.7 in ascending order, respectively. 6%, 8% and 10% CR modification induce 1.67, 2.04 and 2.57 times higher value than the rutting parameter of neat bitumen. Using Evotherm with the CR modification does not change the performans of only CR modified binder. The binders expected to have low phase angle which indicates more flexible behaviour. The phase angles decrease with the increse of CR content and the use of Evotherm along with the CR modification slightly contributes to this reduction.

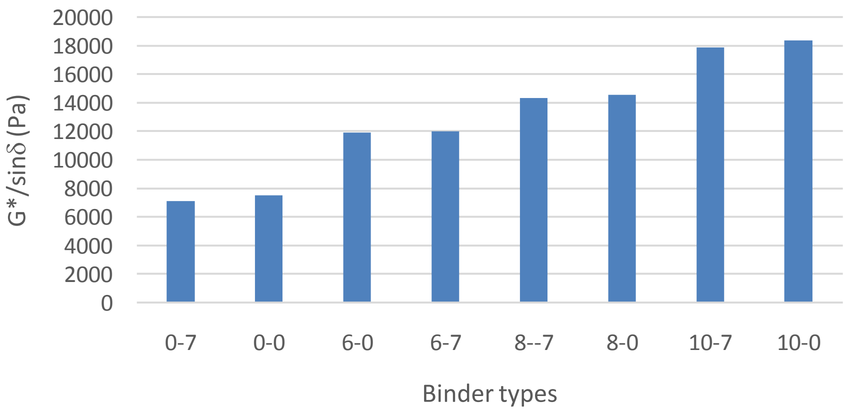

Fig 6: The variation on rutting parameters of binder at 52 ºC.

ISSN 2349-6193
Impact Factor: 3.866
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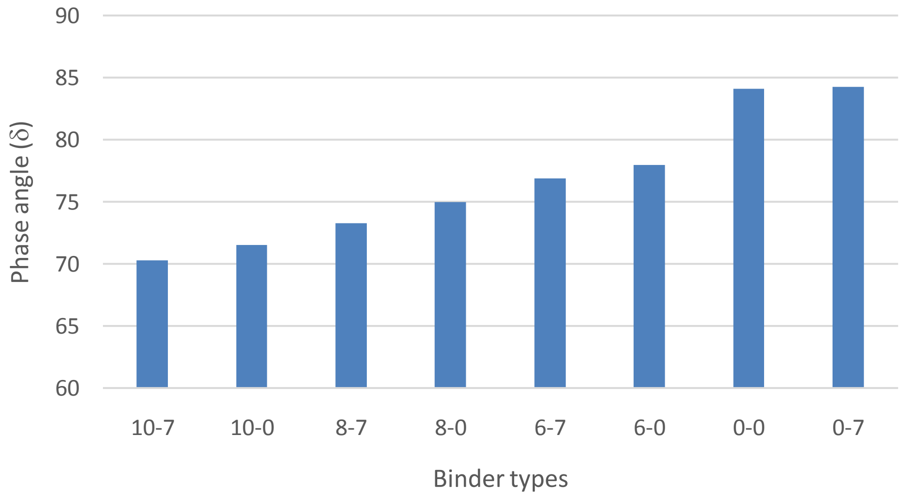

Fig 7: The variation on phase angles of binder at 52 ºC.

The mixing-compaction temperatures of binders also determined with DSR test apart from the rotational viscosity test. The obtained results from the DSR and viscosity test are given comparatively in Table 5. While there is no significant differences between the temperatures obtained by DSR and RV test for neat bitumen, DSR test gives markedly low mixing-compaction temperatures for the modified binder compared to values obtained by rotational viscosity test.

Table 5: Mixing-compaction temperatures of binder obtained by DSR and RV test.

	Mixing temperature (ºC)			Compaction temperature (ºC)		
Binder types	DSR test	RV test	Difference	DSR test	RV test	Difference
0-7	156.8	156.6	0.2	143.3	144	-0.7
0-0	159.6	158.7	0.9	144.9	145.6	-0.7
6-7	166.7	178.3	-11.6	152.7	163.2	-10.5
6-0	170.3	176.6	-6.3	155.7	162.5	-6.8
8-7	169.4	192.7	-23.3	156.1	174.8	-18.7
8-0	175.8	184	-8.2	161.6	168.8	-7.2
10-7	174.8	198.6	-23.8	160.7	180.6	-19.9
10-0	180.7	198.6	-17.9	165.8	180.9	-15.1

The BBR test was carried out at -15 in order to determine the low temperature behavior of binders. The results are given in Table 6.

Table 6: BBR test results.

Binders	St (Mpa)	m-value	Deflection (mm)
0-0	212.5	0.360	0.382
0-7	223.3	0.362	0.362
6-0	201.3	0.327	0.400
6-7	268.2	0.418	0.325
8-0	172.1	0.330	0.469
8-7	198.3	0.356	0.410
10-0	156.7	0.346	0.477
10-7	169.6	0.344	0.470

ISSN 2349-6193
Impact Factor: 3.866

The variation of coefficient λ which is the S_t / m-value ratio are given in Fig.8. The smaller value which represents a better low temperature performance was obtained by 10% CR modified binder. 8% CR modified binder also exhibit significantly better performance than neat bitumen. The use of Evotherm with 8% and 10% CR does not contribute to low temperature behavior of CR modification but provides more flexible behavior than the neat bitumen showing an improved resistance to low temperature cracking.

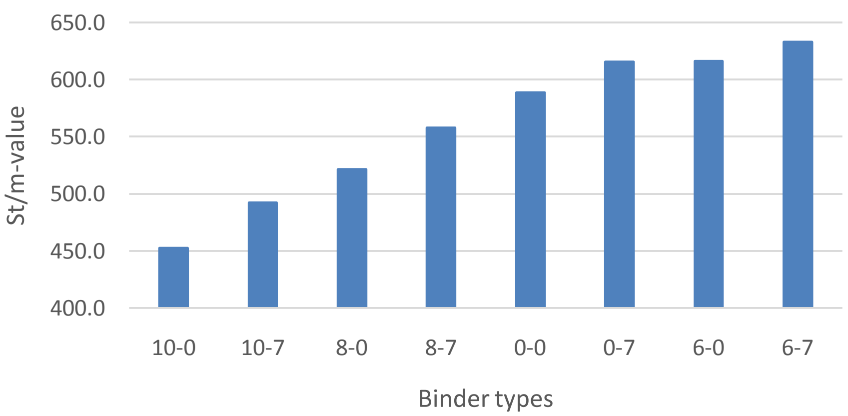

Fig 8: The variation on St/m-value of binder at -15 ºC.

CONCLUSION

In this study, conventional and rheological properties of the binders modified with CR and Evotherm was evaluated. Based on the performed tests, the following conclusions could be drawn.

CR modification is more effective on the increase of softening points than the Evotherm modification. 0.7% Evotherm does not alter the softening point of the binder modified with any content of CR. Both the individual and common usage of Evotherm with CR has very few effects on reducing the viscosity.

It was determined from the DSR test that rutting parameters are getting closer to each other and the binder types comes down with the increase of temperature. Using Evotherm with the CR modification does not change the performans of only CR modified binder at DSR test. While there is no significant differences between the temperatures obtained by DSR and RV test for neat bitumen, DSR test gives markedly low mixing-compaction temperatures for the modified binder compared to values obtained by rotational viscosity test. The use of Evotherm with 8% and 10% CR does not contribute to low temperature behavior of CR modification but provides more flexible behavior than the neat bitumen.

Evotherm is presented as warm-mix additive by ensuring lower mixing-compaction temperatures at mixtures tests in literature. However this study also showed that the effects of Evotherm cannot be evaluated by binder tests in terms of recognize it as a warm-mix additive.

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