Effects of paraffin on low temperature properties of SBS modified binder

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ABSTRACT

The method applied most to improve engineering properties of bituminous hot mixtures which are used in coating layer is the enhancement of bitumen's properties with various additive materials. Polymer based additive materials are generally used for bitumen modification. Among these additive materials, styrene-butadiene-styrene (SBS) block copolymers are mostly used. It was determined that SBS increases the resistance of mixtures against to rutting and fatigue at high temperatures. However it was determined that increased content of SBS caused both worsening of the low service temperature and also workability of the mixtures. It is reported that a rubbery network is created which improves elastic response and enhance low temperature cracking resistance in case the SBS-rich phase forms. It is known that using paraffin's property of reducing viscosity and increasing softening point together with SBS modification which causes increase in viscosity, enhances this combined binder's properties of high temperatures and workability; however there exists no study related to the behavior of this combined binder at low temperatures, in literature. In this study the effect of SBS and paraffin modification on base bitumen were investigated. Firstly the bitumen modified individually with SBS and paraffin was evaluated in terms of Bending Beam Rheometer (BBR) test. Then, the bitumen including both SBS and paraffin in different contents was tested. Including the three different SBS and paraffin content and also base bitumen, totally 16 different combination were evaluated. In conclusion, it was determined that the ratio of stiffness to m-value gives better result in evaluation of low temperature behavior. At low temperatures, it was determined that stiffness increase with increasing additive rates; however this increase is much more in paraffin modification, in particular, SBS addition at low ratio decreases the increase of stiffness caused by paraffin modification.

Keywords: Additives, Low-Temperature, Stiffness

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Abstract

It is known that using paraffin's property of reducing viscosity and increasing softening point together with SBS modification which causes increase in viscosity enhances this combined binder's properties of high temperatures and wokability; however there exists no study related to the behavior of this combined binder at low temperatures, in literature. In this study the effect of SBS and paraffin modification on a base bitumen were investigated. Firstly the bitumen modified individually with SBS and paraffin was evaluated in terms of Bending Beem Rheometer (BBR) test. Then, the bitumen including both SBS and paraffin in different contents was tested. Including the three different SBS and paraffin content and also base bitumen, totally 16 different combination were evaluated. In conclusion, it was determined that the ratio of stiffness to m-value gives better result in evaluation of low temperature behavior. At low temperatures, it was determined that stiffness increase with increasing additive rates; however this increase is much more in paraffin modification, in particular, SBS addition at low ratio decreases the increase of stiffness caused by paraffin modification.

Keywords: SBS, Paraffin, Low temperature, Stiffness

1. Introduction

While drivers, as road users, demand roads which are smooth, comfortable, having high shear resistance, with fast access, and whose transportation costs and noise level is less; road building authorities target the roads which are durable, requires minimum maintenance, resistant to permanent deformations and low temperature cracks, long-lasting. The method applied most to improve engineering properties of bituminous hot mixtures which are used in coating layer is the enhancement of bitumen's properties with various additive materials. Polymer based additive materials are generally used for bitumen modification. Among these additive materials, styrene-butadiene-styrene (SBS) block copolymers are mostly used. It was determined that SBS increases the resistance of mixtures against to rutting and fatigue at high temperatures [1-3]. However it was determined that increased content of SBS caused worsening of the low service temperature [4]. It is reported that a rubbery network is created which improves elastic response and enhance low temperature cracking resistance in case the

SBS-rich phase forms [5]. The most frequently emphasized conclusion in studies conducted using paraffin was reported as the lowered viscosity as a result of paraffin modification [6-9]. The paraffin modified mixture of bitumen (2% by weight) was reported to possess the same workability characteristics as that of the hot mixture at a temperature, which is 30^{o}C lower than that of the hot mixture [10]. Difenderfer and Hearon [11] reported that the laboratory mixtures prepared with paraffin modification performed 22% better than hot mixtures and 10% better than the core samples in terms of fatigue. It was stated that paraffin modification has positive influences on mean and high temperature behaviors; however it negatively affects the low temperature behavior especially at and above 3% rate [12].

According to the BBR test it is reported that when paraffin content increases, the stiffness of bitumen at low temperature is also increased which is more apparent at lower temperatures. The variation of stiffness and m-values shows that increasing paraffin percentage exacerbates the performance of modified bitumen at low temperatures [13]. It is predicted that more than 3% paraffin modification had a negatively impaction on the thermal-cracking properties of warm modified binders [14].

In this study, it was tried to be determined how the binders low temperature behavior is affected in the case of using SBS and paraffin additions at various rates both separately and in same mixture.

2. Low temperature property

Low-temperature cracking, commonly termed thermal cracking, is the most recognized non-load associated distress [15]. Thermal cracking is caused by thermal shrinkage induced stresses resulting from environmental cooling [16]. The other factors such as stiffness, consistency and temperature susceptibility of the bitumen also effect the low temperature cracking. These types of cracks induced to a rapid deterioration of pavement by leading to introduce the water into pavement layers. A number of experimental methods have been developed over the years to characterize asphalt binders' behavior at low temperatures and to select materials with better performance. Creep test is used commonly for evaluating the low temperature property of viscoelastic materials.

The BBR is used to measure the stiffness of binders at very low temperatures. The test uses engineering beam theory to measure the stiffness of a small asphalt beam sample under a creep load. A creep load is used to simulate the stresses that gradually build up in a pavement when temperature drops. Two parameters are evaluated with the BBR. *Creep stiffness* (St) is a measure of how the asphalt resists constant loading and the *m-value* is a measure of how the asphalt stiffness changes as loads are applied. The creep stiffness of the asphalt beam sample at any time of loading (t) is determined by:

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

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

In Superpave, to prevent thermal cracking, creep stiffness has a maximum limit of 300 MPa, m-value has a minimum limit of 0.300. For grading asphalt binders the performance properties that are required of the binder are set and the temperatures at which these performance properties are satisfied establishes the grade of the binder [17]. The creep stiffness is an indicator of the specimen's ability to resist the constant creep load and the creep rate is the rate at which the creep stiffness changes with loading time [18]. Liu et all.[19], defines the coefficient λ = St/m. The smaller the λ, the better the low temperature performance is.

3. Materials and Method

An asphalt cement, B 50/70, obtained from Turkish Petroleum Refineries was used as base bitumen. The SBS polymer used was supplied by the Shell Chemicals Company. The additive is a linear SBS polymer in powder form that consists of different combinations polystyrene (31%) and polybutadiene blocks of a very precise molecular weight [20]. 2%, 3% and 4% SBS content were used for the SBS modification.

The warm-mix-additive used in the experiment is FT paraffin which has organic origin and supplied by Sasol. It is long chain aliphatic hydrocarbons from coal gasification process in the production of Fischer–Tropsch, also known as FT paraffin wax [21]. During the Fischer–Tropsch process, carbon monoxide is converted into a mixture of hydrocarbons having molecular chain lengths of 1–100 carbon atoms and greater. Paraffin is added to base bitumen as 2%, 3% and 4% for the paraffin Modification. SBS and paraffin additives are used both separately and together in same binders. The effects of these additives on binder's low temperature property namely Bending Beem Rheometer (BBR) were examined. However, one should notice that unlike SHRP requirements, these determinations were made on unaged binders. The modified bitumens were produced with a laboratory-scale mixing device (Fig.1) with a four-blade impeller (IKA) at a temperature of 180 °C for 1 h at a rotation speed of 1000 rpm. In the study totally 16 different binder given in Table 1 including base bitumen were evaluated.

Fig.1. Binder mixer.

Table 1. The representative of binder combinations.

	The additive content used by the binder weight (%)															
SBS	0	0	0	0	2	2	2	2	3	3	3	3	4	4	4	4
Paraffin	0	2	3	4	0	2	3	4	0	2	3	4	0	2	3	4
Symbol	0S-0P	0S-2P	0S-3P	0S-4P	2S-0P	2S-2P	2S-3P	2S-4P	3S-0P	3S-2P	3S-3P	3S-4P	4S-0P	4S-2P	4S-3P	4S-4P

4. Results and Discussion

From the BBR tests at –25 °C, the shrinkage resistance parameters, stiffness and m-value, of the control and the modified binders were calculated, and the results are shown in Table 2.

Table 2. BBR test results

	0S-0P	0S-2P	0S-3P	0S-4P	2S-0P	2S-2P	2S-3P	2S-4P	3S-0P	3S-2P	3S-3P	3S-4P	4S-0P	4S-2P	4S-3P	4S-4P
St (MPa)	279.6	330.0	371.5	374.9	300.9	309.0	331.4	370.5	321.0	347.6	371.2	414.0	367.1	371.7	394.5	454.0
m-value	0.296	0.272	0.258	0.252	0.294	0.283	0.239	0.237	0.304	0.223	0.219	0.222	0.313	0.229	0.221	0.227

It was seen from the Table 2 that the creep stiffness of all binders except pure binder exceed 300 MPa even at low additive content. The effects of individual usage of the additive on St, m-value and St/m-value are given in Fig.2, Fig.3 and Fig.4 respectively.

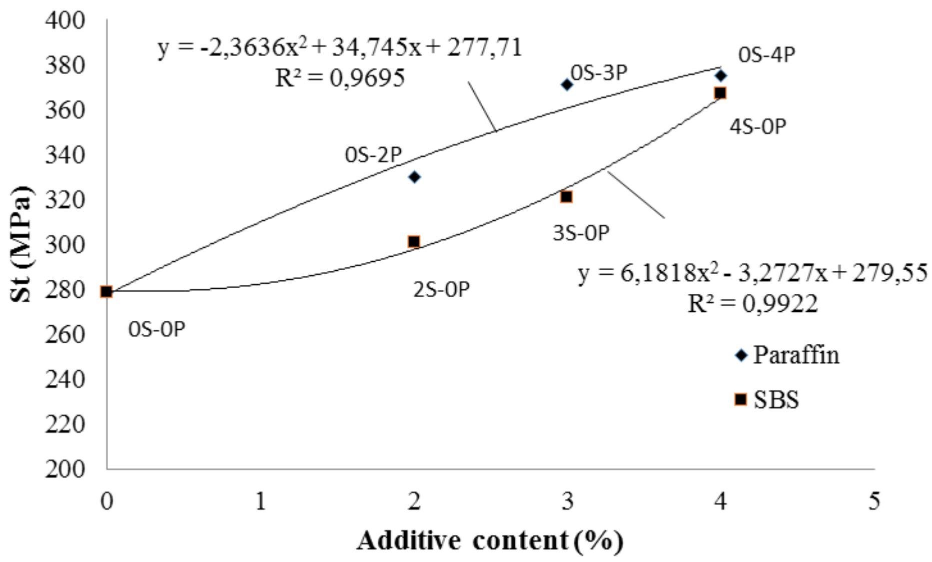

Fig. 2 The relation between additive content and St

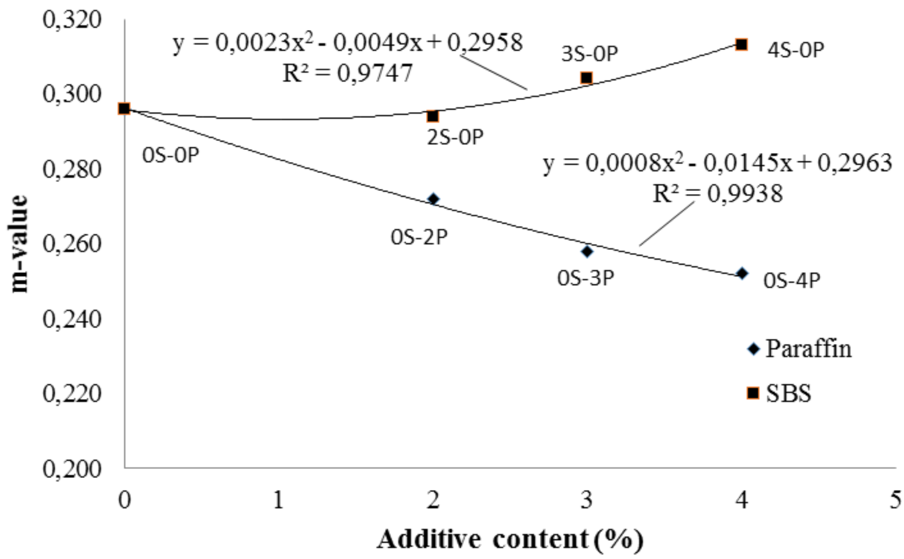

Fig. 3 The relation between additive content and m-value

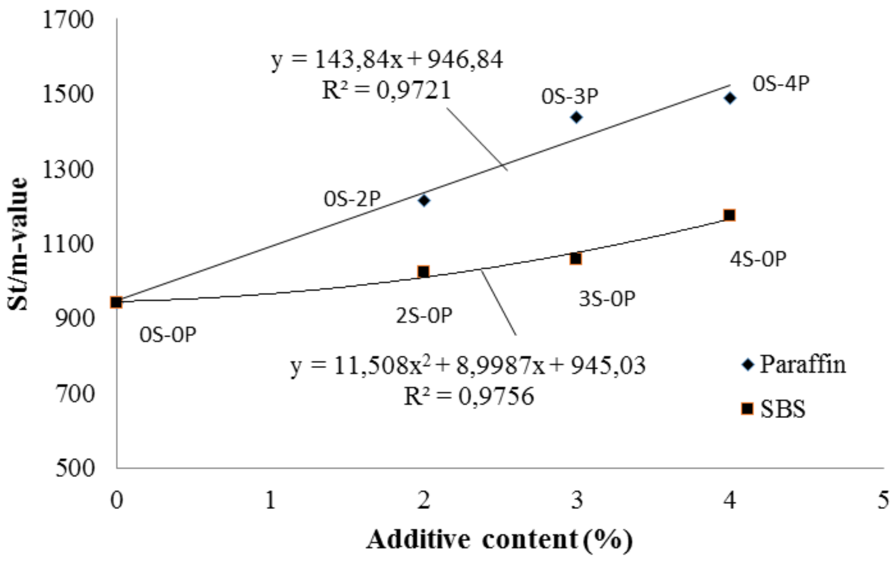

Fig. 4 The relation between additive content and St/m-value

It was determined that the stiffness were increased with the additive content for both additive. This stiffness-increase raises with the increase of additive rate in the SBS modification, and decreases in the paraffin modification. The paraffin in low additive rate is more effective on the stiffness-increase when compared with the SBS modification. With increasing additive rate, the difference between the stiffness of paraffin and SBS modified binders considerably decreases. The rate of 4% paraffin and 4% SBS increases the binder's stiffness 34% and 31% with respect to pure binder, respectively. When m-values are evaluated; it is seen that SBS modification does not keep stiffness on the body as paraffin modification, by giving higher m-value. 3% SBS modification has similar m-value with the pure binders. m-value of 4% SBS modified binder is 6% high than the one of pure binder. While the SBS modification does not present a bad performance in terms of m-values from the base binder, the m-values has shown a continuous decrease with the increase of the additive rate in the paraffin modification. The 4% paraffin modification gave 15% lower m-values when compared with the base binder.

When the change of St/m values which resembles elastic behavior best, with additive ratio is evaluated; it is seen that St/m values of each modified binder increase with the additive content. However the trend is different from the St results. In this evaluation it was determined that paraffin modification increase more with additive content according to SBS modification and therefore it exhibits less elastic behavior. The difference between the stiffness of SBS and paraffin modified binder constantly rise with the increasing of additive content.

The flexible materials can exhibit much deflection at low temperatures. In this respect it is obvious that the deflection values of paraffin modified binders decrease steady with the additive content at low temperatures. These indicate a disadvantage to dissipate the energy induced from loads for both additive especially paraffin.

The variation on the St and m-value of the all binders are given in ascending order in Fig.5 and Fig.6. As 2% SBS modified binder gives the minimum stiffness and accordingly the most elastic behavior with respect to St values, 4S-4P binder gives the highest stiffness within the modified binders. Using SBS together with paraffin decreases the stiffness-increase that is caused by the paraffin. The 2S-2P binder gives lower stiffness values than the 0S-2P binder; and the 2S-3P binder gives lower values than the 0S-3P binder. However, the SBS cannot be much effective on the stiffness decrease caused by the paraffin used in a higher rate. The 2S-4P binder gives almost the same stiffness values with the 0S-4P binder. Only the 2S-2P, 2S-3P and 3S-2P binders in which the additives were used together could give lower stiffness values than the 4S-0P binder (the binder with only 4% SBS).

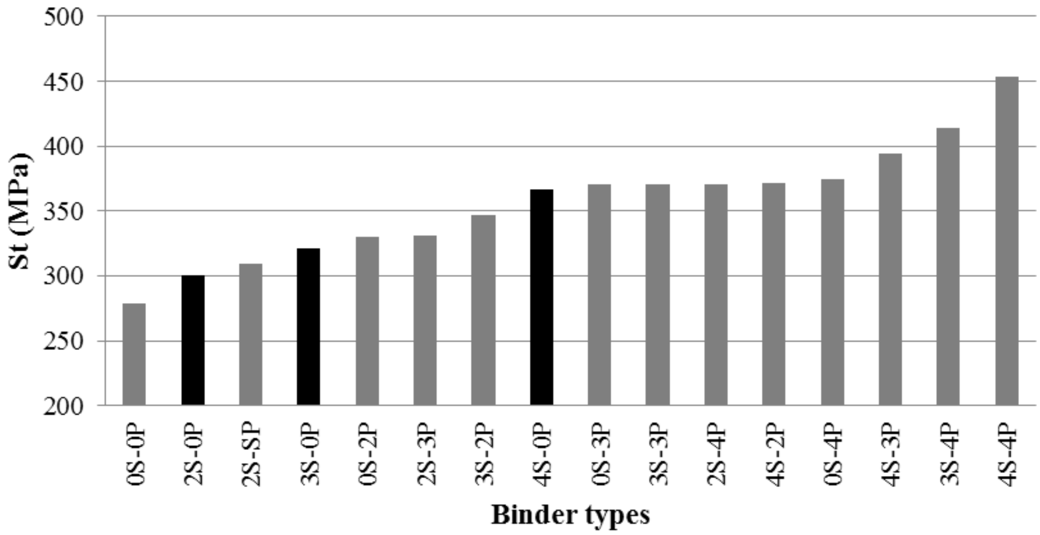

Fig.5 The change on St values of all binders

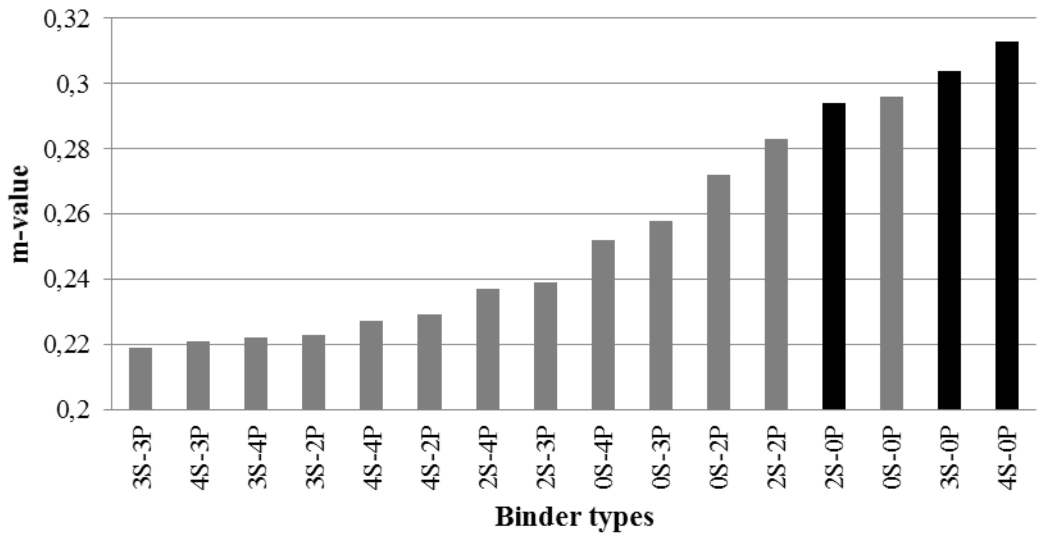

Fig.6 The change on m-values of all binders

It is seen from the Fig.6 that all binders except 3S-0P and 4S-0P give lower m-value than that of the base bitumen. Within these low values; 2S-2P binder gave the maximum m-value where additives were used together. Highest m-value values were obtained for only SBS modified binders. Using SBS together with paraffin modified binders gives positive results in terms of stiffness; however, in terms of the m-values, using SBS together with paraffin modification (except for the 2S-2P) decreases the m-value, and the result is a negative effect.

Since the binder which gives both maximum St value and m-value, comment about if it is rigid or elastic cannot be done. Therefore; St/m values of the binders were evaluated in order to make more accurate evaluation. The changes of St/m values of all binders were given from smallest to biggest, respectively in Figure 7. As seen from the figure; while only the binders modified with SBS have the minimum St/m values, that is, maximum elasticity values, only the binder modified with 4% paraffin and 4% SBS gave the most rigid behavior. Using 2% SBS with paraffin addition does not remarkably contribute to the stiffness increase. Besides using 2% SBS with 2% and 3 % paraffin (2S-2P and 2S-3P binders) gives lower values than the binders modified only 2% and 3% paraffin (0S-2P and 0S-3P binders). On the other hand the usage of SBS with the paraffin more than 4% also cause an additional stiffness increase.

In case 2% paraffin is used together with 3% and 4% SBS modification, the St/m-values increase in 47% and 38%, respectively. In case 3% paraffin is used with the same binders, these values become 60% and 51%. In case 4% paraffin is used with the same binders, these values become 76% and 70%. In mixtures in which the additives are used together, paraffin is more effective on the decrease that occur in the elasticity than the SBS. 3% SBS + 2% paraffin binder exhibited a rigidity in between minimum and maximum values within the combinations which are taken into consideration.

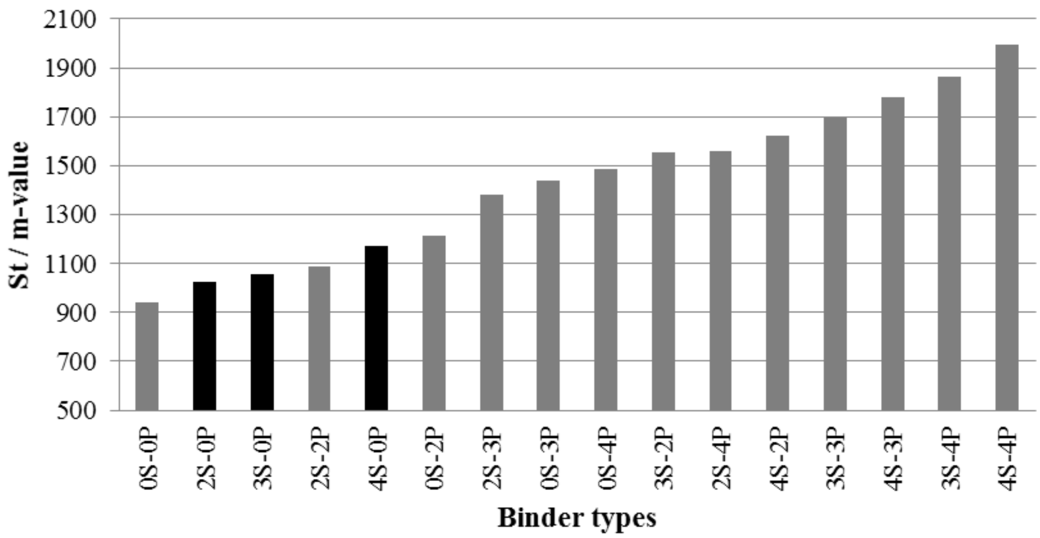

Fig. 7 The variation on S_t/m-value of all binders.

Conclusion

In this study, an evaluation of using paraffin and SBS modifier in asphalt blend is presented relevant to low temperature properties. The study is carried out at –25 °C based on BBR test conducted in the laboratory on modified binders using each modifier separately and combined in the same base binder.

The stiffness increase with the additive content for both the two modifiers. The SBS is effective in this stiffness increase in high additive rates, and the paraffin is effective in low additive rates; however, in high additive rate, both modifiers have the same effect.

In terms of comparing two modifiers separately paraffin yields higher stiffness than that of the SBS modified binders. When m-values are considered; it is seen that, similarly, SBS modification does not keep stiffness as paraffin modification, by giving higher m-values. 3% SBS modification has similar m-value with pure binder. The m-values in the SBS modification increase even if just a little when compared with the pure binder; and they decrease continuously in the paraffin modification with the additive content. m-values showing the different trend with creep stiffness along with increasing additive ratio, evaluation of St/m-value give more rational result. According to St/m-value, a continuous increase occurs with the increase of additive ratio which is more pronounced for paraffin modification. None of the modified binders showed elastic behavior as much as the base binder. It has been determined that the paraffin, which is used as the warm mix additive in bituminous mixtures, and which is very effective in decreasing the viscosity, does not give positive results in terms of low temperature behavior, and that using 2% SBS together with %2 and %3 paraffin could decrease the elasticity-loss which is caused by the paraffin at a certain amount; however, using the additives together after the rate of 3% affect the low temperature behavior negatively at a significant level.

It must be considered that the results obtained in this study are only valid for the bitumen and additive types used in this study. The study can be enlarged by taking up various types of bitumen and additive in further studies. Furthermore a comprehensive study can be carried out by evaluating the image properties of modified binder in the context of consistency between the bitumen and additives.

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