

The Effect of SBS and Wax Modification on Stability and Stiffness of Stone Mastic Asphalt

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Abstract

Increasing traffic load and flow make the additive usage and new gradation quests necessary for more quality roads. In this respect using polymer additives and stone mastic asphalt are presented as a solution. However the need for using hard and polymer modified binders in stone mastic asphalt mixtures reduces workability and elevates the costs considerably. In this study the effects of using styrene-butadiene-styrene (SBS) and Sasobit both separately and together in the hot mixtures were evaluated. B 50/70 base bitumen and limestone aggregate were used for preparing the mixtures. Marshall stability and indirect tensile stiffness modulus test were applied to the mixtures prepared by base and modified binders. The Marshall test were carried out for both unconditioned and conditioned samples and hence retained Marshall stabilities was also determined. Stiffness modules were determined at three different temperatures. SBS and Sasobit together in the same mixture significantly improves stability and stiffness of the mixtures compared to containing only SBS and Sasobit. Sasobit modification increases the effectiveness of the SBS modification with respect to mechanical properties except moisture resistance.

Key words: Hot bituminous mixture, SBS, Sasobit, Stability, Stiffness.

SBS ve Wax Modifikasyonunun Taş Mastik Asfaltın Stabilite ve Rijitliğine Etkisi

Özet

Artan trafik yükleri ve miktarı daha sağlam yollar için katkı kullanımını ve yeni gradasyon arayışlarını gerektirmiştir. Bu bağlamda polimer katkılarının kullanımı ve taş mastik asfalt bir çözüm olarak sunulmaktadır. Fakat taş mastik asfaltlarda sert ve polimer modifiyeli bağlayıcı kullanılması gerekliliği işlenebilirliği azaltmakta ve maliyetleri artırmaktadır. Bu çalışmada sıcak karışım içinde styrene-butadiene-styrene (SBS) ve Sasobitin hem ayrı hem de birlikte kullanılmalarının etkileri incelenmiştir. Karışımların hazırlanmasında B 50/70 bitümü ve kireç taşı agrega kullanılmıştır. Katkısız ve polimer modifiyeli karışımlara Marshall stabilite ve indirek çekme rijitlik modülü deneyleri uygulanmıştır. Marshall testi hem koşullu hem de koşulsuz numunelere uygulanarak kalıcı Marshall stabilite de tespit edilmiştir. Rijitlik modülü üç farklı sıcaklıkta belirlenmiştir. Aynı karışım içinde SBS ve Sasobitin birlikte kullanılması stabilite ve rijitliği ayrı kullanılmalarına göre önemli derecede iyileştirmiştir. Nem hassasiyeti dışında mekanik özellikler açısından Sasobit, SBS katkısının etkinliğini artırmıştır.

Anahtar kelimeler: Sıcak bitümlü karışım, SBS, Sasobit, Stabilite, Rijitlik.

1. Introduction

Polymer based additives are mixed with bitumen and bitumen containing hot mixtures in order to increase their resistance to heat and traffic load. Among those additives, styrene-butadiene-styrene (SBS) block copolymers are frequently utilized. SBS block copolymers, which are categorized as elastomers among polymer type materials, improve the elasticity of

the bitumen binders. A number of studies reported improved resistance to rutting and fatigue at elevated temperatures through the use of SBS [1-3].

Using SBS in hot mixtures improves the mechanical properties of mixtures, besides it requires high mixing and compaction temperatures due to increasing viscosity. New technologies have been developing to reduce the mixing and compaction temperatures of mixtures without any compensate in the mixture

mechanical properties. The additives induced reduction in mixing-compaction temperatures enable to saving energy and decreasing carbon release, extending the construction season, allowing the mixture to be transported to longer distances and preventing the aging of the binder during the hot mix asphalt (HMA) production. A frequently used warm mixture additive recently is Sasobit. Sasobit is an additive comprised of a long aliphatic hydrocarbon chain produced by the Fischer-Tropsch synthesis of coal or from natural gas. The most frequently emphasized conclusion in studies conducted using Sasobit was reported as the lowered viscosity as a result of Sasobit modification [4-7]. It is stated that warm mix additives are more effective with respect to rheological properties when used with polymer modification [8]. The Sasobit 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°C lower than that of the hot mixture [9]. Difenderfer and Hearon [10] reported that the laboratory mixtures prepared with Sasobit modification performed 22% better than hot mixtures and 10% better than the core samples in terms of fatigue. Jamshidi *et al.* [11] reported that Sasobit modification did not affect the volumetric properties and the optimum bitumen content in the original mixtures while providing low aging properties thus higher fatigue life owing to the low treatment temperature and that recycled materials could be utilized in higher ratios through the use of Sasobit. Warm mix asphalt additives especially Sasobit was reported to improve the crumb rubber modified binders' resistance to rutting and greatly improved high temperature level of performance graded crumb rubber modified binders [12].

2. Material and Methods

2.1. Materials and sample preparation

Table 2. Binder properties.

Mix types	0-0	3-0	0-3	3-3
Penetration (1/100 cm)	51.2	35.7	40.7	31.7
Softening point (°C)	52.2	69.3	77.4	80.2
PI	-0.61	1.89	3.44	3.22
Viscosity @135 °C	0.600	1.775	0.462	1.463
Viscosity @165 °C	0.175	0.462	0.137	0.387

Binder specimens were prepared using B 50/70 asphalt cement obtained from the Batman Petroleum Refinery of Turkey. The selected SBS polymer was Kraton D-1101 supplied by the Shell Chemicals Company. Sasobit was obtained from the Sasolwax. The blends of asphalt binder were produced with the selected modifiers by using a laboratory scale-mixing device equipped with a four-blade impeller as shown in Figure1. The blends were mixed at a temperature of 175°C and a rotational speed of 1,000 rpm for 1 hour.



Figure1. Laboratory-scale mixing device.

The concentration of SBS and Sasobit in the base bitumen was selected as 3% by weight of the base bitumen based on the outcomes of previous studies [13,14]. Table 1 represents the tested binder combinations. The properties of the bitumens modified with separate and mixed modifiers in the same blend were given in Table 2.

Table 1 Mixture combinations.

	Additive percentage by weight of bitumen			
SBS	0	3	0	3
Sasobit	0	0	3	3
Representation	0-0	3-0	0-3	3-3

Limestone aggregate was used in the asphalt concrete mixture. The gradation and the properties of the aggregate are given in Table 3. A crushed coarse and fine aggregate, with a maximum size of 19 mm, was selected as the stone-mastic-asphalt (SMA) mixture. The asphalt mixture was designed in accordance with the standard Marshall mix design procedure. The specimens were compacted by using 50 blows on each side of cylindrical samples in 101.6 mm diameter and 63.5 mm thickness. Mixing and compaction temperatures, which were determined according to viscosity values, were taken into account during the sample

preparation. The mixing and compaction temperatures were determined for mixtures including different bitumens by using the 170 ± 20 and 280 ± 30 cP viscosity values, respectively [15]. The optimum bitumen content was found to be 6.5% by weight of aggregate for the unmodified asphalt mixes. This ratio was chosen for all mixtures so that the amount of bitumen would not confound the analysis of the test data. The physical properties of the mixtures such as air voids (V_a), voids filled with asphalt (V_{FA}), voids in mineral aggregates (V_{MA}) bulk specific gravity (G_{mb}) and maximum specific gravity (G_{mm}) are given in Table 4.

Table 3. Physical properties of the aggregate.

Sieve size (mm)	19.1	12.7	9.52	4.76	2.00	0.42	0.17	0.075
Passing (%)	100	95.0	62.5	32.5	25.0	17.0	13.0	11.0
Specific gravity (g/cm^3) (Coarse, fine, filler)	2.533 2.619 2.732							
Abrasion loss (%) (Los Angeles)	25							
Frost action (%) (with Na_2SO_4)	2.5							
Stripping resistance (%) (Nicholson)	70-75							

Table 4. Design values of the mixture.

Mix.types	W_a (%)	V_a (%)	V_{MA} (%)	V_{FA} (%)	G_{mb}	Mixing Temp. ($^{\circ}\text{C}$)	Compaction Temp. ($^{\circ}\text{C}$)
0-0	6.5	2.94	14.19	79.29	2.350	165.8	152.8
0-3	6.5	2.91	14.16	79.48	2.343	159.9	147.3
3-0	6.5	3.29	14.51	77.32	2.342	191.8	178.1
3-3	6.5	3.24	14.46	77.60	2.343	186.9	173.4

3. Marshall stability and flow test

The specimens were divided into two groups. The first group of specimens was immersed in water at 60°C for 30 min and then loaded to failure by using curved steel loading plates along with the diameter at a constant rate of compression of 51 mm/min. The second group of specimens (conditioned specimens) was placed in water bath at 60°C for 24 h. And then the same loading was applied as described above. The ratio of stability (kN) to flow (mm), stated as the Marshall quotient (MQ) and as an indicator of stiffness of the mixes, was determined. It is well recognized that the MQ is a measure of the materials' resistance to shear stresses, permanent deformation and hence rutting [16]. High MQ values indicate a mix with high stiffness and with a greater ability to spread the applied load and resistance to creep

deformation. The ratio of stability to flow of unconditioned and conditioned specimens was represented by MQ1 and MQ2 respectively. The retained Marshall stability (RMS) was then found by using the average stability of each group by using the following formula:

$$RMS = 100(MS_{cond.} / MS_{uncond.}) \quad (1)$$

where RMS is the retained Marshall stability, $MS_{cond.}$ is the average Marshall stability for conditioned specimens (kN) and $MS_{uncond.}$ is the average Marshall stability for unconditioned specimens (kN).

The Marshall stabilities and the flows are given in Table 5 for each mixture. The values are the average of the three samples. The stability of the unconditioned 0-3, 3-0, and 3-3 mixtures are 2.5%, 7.34% and 14.6% higher than those of the control mixture (0-0) respectively. These values

are arranged as 22.6%, 24.6% and 29.5% for conditioned samples. The effect of the additives on improving stability was more pronounced in conditioned samples. The reason was that a 24% reduction was measured in stability post-conditioning for the pure mixture whereas the reduction ranged between 8-14% in additive modified mixtures. The 3%SBS +3% Sasobit modified mixture gives the highest MQ values for both unconditioned and conditioned form. It is assumed that using these additives together in the mixture stiffen the specimens and besides give high stability prevent high flow so that provides high MQ. The lowest retained Marshall stability which was 76% was measured for the pure mixture. The comparison of the MQ values rather than the Marshall stabilities in which the flow was also considered highlighted the effectiveness of the additives more clearly.

The retained Marshall stability values of the modified mixtures did not vary considerably although the highest value of 91% was measured for the 3% Sasobit modified mixture. The reason was thought to be the viscosity lowering properties of Sasobit thus facilitating improved adhesiveness. The only SBS modified only Sasobit and modified mixtures gives 15% and

20% higher RMS values than those of the control mixture. The combined effect of additives increase the RMS values as 18%.

It was determined that while the SMA mixtures give lower stability than those of dense graded asphalt mixtures, it could carry the maximum load so long time as it seen in Figure 2. (The stability-flow curve of dense graded asphalt samples is belong to mixture that prepared according to technical specification of Republic of Turkey General Directorate of Highways (Type-2). The stability-flow curve of SMA samples is belong to 0-0 mixture used in this study).

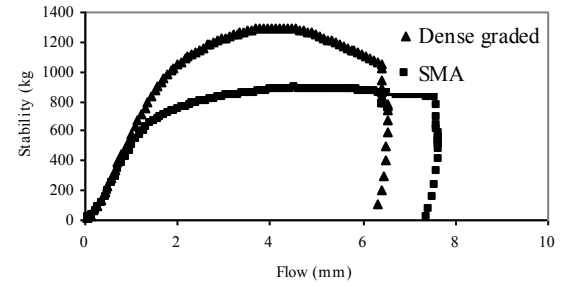


Figure 2. Marshall stability-deformation relation of SMA and dense graded mixture.

Table 5 Marshall stability test results.

Mixture types	Stability, 30 min. at 60 °C MS ₁ (kN)	Flow, F ₁ (mm)	MQ ₁ MS ₁ /F ₁	Stability, 24 h. at 60 °C MS ₂ (kN)	Flow, F ₂ (mm)	MQ ₂ MS ₂ /F ₁	RMS MS ₂ /MS ₁
0—0	8.69	4.82	1.80	6.65	5.65	1.18	76.52
0—3	8.91	4.41	2.02	8.16	6.52	1.25	91.58
3—0	9.33	4.03	2.32	8.29	5.89	1.41	88.85
3—3	9.97	4.16	2.40	8.63	4.7	1.84	86.56

4. Indirect tensile-stiffness-modulus test

The stiffness modulus test of asphalt mixtures measured in indirect-tensile mode is the most popular form of the stress-strain measurement methods used to evaluate the elastic properties of these mixtures. The indirect tensile stiffness modulus (ITSM) test defined by BS DD 213 is a nondestructive test. ITSM, which is considered as a very important performance characteristic for pavement formulation is defined as:

$$S_m = P(R + 0.27) / tH \quad (2)$$

where, S_m is stiffness modulus in MPa, P is the peak value of the applied vertical load (repeated load) (N), H is the mean amplitude of the horizontal deformation (mm), t is the mean thickness (mm), and R is the Poisson ratio (here assumed to be 0.35). The test was performed with deformation controlled using the universal testing machine (UTM, Figure3). Target deformation was selected as 6 μ m. During testing, the rise time, which is the time passes for the applied load to increase from zero to a maximum value, was set at 124 ms. The load-

pulse application was set to 3.0 s. The test was performed at 20, 25, 30 °C.

Three specimens were tested for each of the control and modified mixtures. In order to obtain a stiffness modulus value for a mixture, each specimen was tested at three different positions and the mean of nine values was used. The stiffness modulus values of all mixtures at 20, 25 and 30 °C are shown in Figure4. The stiffness modulus of the mixtures were determined to be lowered with increasing temperature and this decrease was more rapid after 30 °C. The stiffness modulus of the samples decreased by 50% in response to an increase in the temperature from 20 °C to 30 °C. The 3%SBS+3% Sasobit mixture had a 2 fold higher stiffness value than that of the control mixture. The use of 3% Sasobit modification with 3% SBS modification increased the stiffness of the mixture by 50% at all temperatures

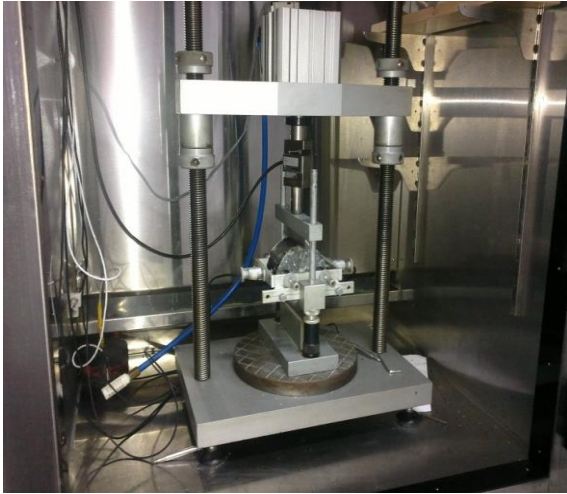


Figure 3. UTM ITSM test set up.

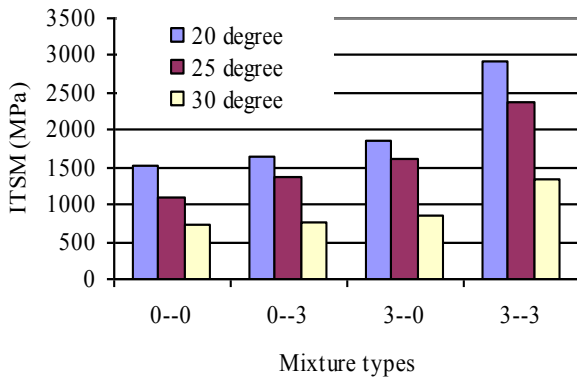


Figure 4. The variation on ITSM values of mixtures.

Another comparison can be made by assessing the force-strain relation of the mixtures at 25 °C, see Figure5. The strain values, which are fixed to 6 μ m, return to zero after the peak force. However, the total area under each curve showing the ability of sample to absorb the elastic energy, are different. Out of all systems studied, 0-0 mixture has the minimum total area 3-3 mixture has the highest total area. Figure 5 shows that, in order to reach the target strain, 3-3 mixture requires 2 times higher force than control mixture necessitates.

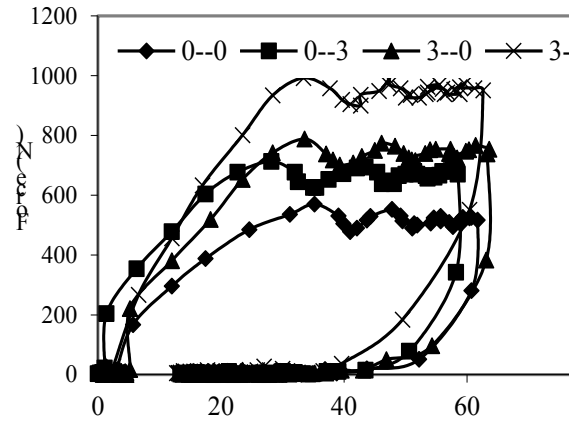


Figure 5. Force-strain relation of mixtures.

5. Conclusion

The objective of this study was to evaluate the effect of using SBS and Sasobit on the resistance to stability and stiffness of stone mastic asphalt. Based on the laboratory test results, the following conclusions were drawn:

The stability of the mixture containing both 3% SBS and 3% Sasobit are 14.6% and 29.5% higher than those of the control mixture for unconditioned and conditioned situation respectively. The effect of the additives on improving stability was more pronounced in conditioned samples. The 3%SBS +3% Sasobit modified mixture gives the highest MQ values. It is assumed that using these additive together in the mixture stiffen the specimens and besides give high stability prevent high flow so that provides high MQ. The highest retained

Marshall stability values as 91% indicating an improved resistance to moisture damage was obtained for 3% Sasobit modified mixture.

The stiffness modulus of the samples decreased by 50% in response to an increase in the temperature from 20°C to 30°C. The 3%SBS+3% Sasobit mixture had a 2 fold higher stiffness value than that of the control mixture. The use of 3% Sasobit modification with 3% SBS modification increased the stiffness of the mixture by 50% at all temperatures.

Based on the laboratory test results, it was concluded that using SBS and Sasobit together in the same mixture significantly improves stability and stiffness of the mixtures containing only SBS and Sasobit. Sasobit modification increases the effectiveness of the SBS modification with respect to mechanical properties except moisture resistance.

6. References

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