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DETERMINATION OF MOISTURE SUSCEPTIBILITY CHARACTERISTICS OF POLYMER MODIFIED HOT-MIXED ASPHALT

(POLİMER MODİFİYE BİTÜMLERLE ELDE EDİLEN SICAK KARIŞIMLARIN SUYA KARŞI DUYARLILIKLARININ İNCELENMESİ)

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ÖZET/*ABSTRACT*

Yol kaplamalarının servis ömrünü ve performansını düşüren erken bozulmalar üzerine birçok çalışma yapılmıştır. Kaplamaların öngörülen süreden daha erken bozulmalarının en büyük sebeplerinden biri de bitümlü kaplamalardaki suya bağlı bozulmalardır. Agrega cinsi, bitümlü bağlayıcı, karışım tasarımı ve yapımı, trafik düzeyi, çevre, bitüme ve/veya agregaya eklenen katkıların özellikleri gibi birçok etken bitümlü kaplamalardaki suya bağlı bozulmaların miktarını etkiler. Bu çalışmanın amacı, elastomerik (SBS) ve plastomerik (EVA) polimer modifiye bitümlerle (PMB) hazırlanan ve farklı agrega türleri (bazalt-kalker agrega karışımı ve yalnız kalker agregası) içeren sıcak karışım asfaltların soyulma potansiyeli ve neme karşı duyarlılık özelliklerinin saptanmasıdır. Hazırlanan örneklerin bu özellikleri, Nicholson Soyulma Deneyi (ASTM D 1664) ve Modified Lottman Test (AASHTO T 283) deneylerinden elde edilen bulgular ile Leica S 8 AP0 Stereo Mikroskobu kullanılarak elde edilen mikroskobik görüntüler yardımıyla değerlendirilmiştir. Deneysel sonuçlar, elastomerik ve plastomerik polimer modifikasyonların suyun asfalt karışımlar üzerindeki etkisini azalttıkları ve kaplamanın neme karşı direncini arttırdıkları göstermiştir. Ayrıca yapılan çalışmalardan elde edilen verilere göre, SBS PMB ile hazırlanan karışımların EVA PMB ile hazırlanan örneklere göre suya karşı bozulmalar üzerine etkisinin daha fazla olduğu saptanmıştır.

Many highway agencies have been experiencing premature failures that decrease the performance and service life of pavements. One of the major causes of premature pavement failure is the moisture damage of the asphalt concrete layer. Many variables affect the amount of water damage in the asphalt concrete layer such as the type of aggregate, bitumen, mixture design and construction, level of traffic, environment and the additive properties that are introduced to the bitumen, aggregate or bitumen aggregate mixture. This study is aimed to determine the effect of additives such as elastomeric (SBS) and plastomeric (EVA) polymer modified bitumen (PMB) on the stripping potential and moisture susceptibility characteristics of hot mix asphalt (HMA) containing different types of aggregate (basalt-limestone aggregate mixture and limestone aggregate). The stripping properties and moisture susceptibility characteristics of the samples have been evaluated by means of captured images and the Nicholson Stripping Test (ASTM D 1664) as well as the Modified Lottman Test (AASHTO T 283) respectively. The results indicated that polymer modification increased the resistance of asphalt mixtures to the detrimental effect of water. Moreover, it was found out that samples prepared with SBS PMB exhibited more resistance to water damage compared to samples prepared with EVA PMB.

ANAHTAR KELİMELER/*KEYWORDS*

Polimer modifiye bitüm, Soyulma, Suya bağlı bozulmalar, Neme karşı hassasiyet
Polymer modified bitumen, Stripping, Water damage, Moisture susceptibility

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1. INTRODUCTION

Environmental factors such as temperature, air, and water can have a profound effect on the durability of asphalt concrete mixtures. In mild climatic conditions where good - quality aggregates and asphalt cement are available, the major contribution to the deterioration may be traffic loading, and the resultant distress manifests as fatigue cracking, rutting (permanent deformation), and raveling (Terrel and Al-Swailmi, 1994). However, when a severe climate is in question, these stresses increase with poor materials, under inadequate control, with traffic as well as with water which are key elements in the degradation of asphalt concrete pavements. Water causes loss of adhesion at the bitumen aggregate interface. This premature failure of adhesion is commonly referred to as stripping in asphalt concrete pavements (Fromm, 1974; Taylor and Khosla, 1983; Kandal et al, 1989). The strength is impaired since the mixture ceases to act as a coherent structural unit. Loss of adhesion renders cohesive resistance of the interstitial bitumen body useless. Water may enter the interface through diffusion across bitumen films and access directly in partially coated aggregate (Stuart, 1990). Water can cause stripping in five different mechanisms such as detachment, displacement, spontaneous emulsification, pore pressure, and hydraulic scour (Terrel and Al-Swailmi, 1994; Taylor and Khosla, 1983; Kiggundu and Roberts, 1988).

Many variables affect the amount of moisture damage which occurs in an asphalt concrete mixture. Some of these variables are related to the materials forming hot mix asphalt (HMA) such as aggregate (physical characteristics, composition, dust and clay coatings) and bitumen (chemical composition, grade, hardness, crude source and refining process). Others are related to mixture design and construction (air void level, film thickness, permeability and drainage), environmental factors (temperature, pavement age, freeze-thaw cycles and presence of ions in the water), traffic conditions and type and properties of the additives (Stuart, 1990).

To alleviate or to control the deformations due to water damage, various researches were performed leading to the utilization of anti-stripping additives (Hunter, 2001).

Anti-stripping additives are used to increase physico-chemical bond between the bitumen and aggregate and to improve wetting by lowering the surface tension of the bitumen (Majidzahed and Brovold, 1968). The additives that are used in practice or tested in the laboratory include: i) traditional liquid additives, ii) metal ion surfactants, iii) hydrated lime and quick lime, iv) silane coupling agents, v) silicone (Stuart, 1990).

Methods of treatment to reduce moisture damage also include the utilization of polymer modified bitumen (PMB) (Martin et al., 2003). Polymer is a derived word meaning many parts. Polymers are made up of many smaller chemicals (monomers) joint together end-on-end. The physical and chemical properties of a polymer depend on the nature of the individual molecular units, the number of them in each polymer chain and their combination with other molecular types.

Two basic types of polymers are used in modified bitumen of road applications: i)elastomers, ii) plastomers.

SBS block copolymers are classified as elastomers that increase the elasticity of bitumen and they are probably the most appropriate polymers for bitumen modification. Although low temperature flexibility is increased, some authors claim that a decrease in strength and resistance to penetration is observed at higher temperatures (Becker et al., 1999).

SBS copolymers derive their strength and elasticity from physical and cross linking of the molecules into a three-dimensional network. The polystyrene end blocks impart the strength to the polymer while the polybutadiene rubbery matrix blocks give the material its exceptional viscosity (Lu and Isacsson, 1995).

EVA based polymers are classified as plastomer that modify bitumen by forming a tough, rigid, three-dimensional network to resist deformation. Their characteristics lie between those of low density polyethylene, semi rigid, translucent product and those of a transparent and rubbery material similar to plasticized PVC and certain types of rubbers (Mahabir and Mazumdar, 1999).

Both SBS and EVA type polymers are usually provided in the form of pellets or powder which can be subsequently diluted to the required polymer content by blending with base bitumen by means of low to high shear mixer. Blending pellets of with base bitumen results in a special polymer concentration suitable for different applications (British Petrol, 1997).

Although, the utilization of PMBs for controlling the moisture damage is limited, there is evidence that some polymers can act as anti-stripping agents (Epps et al., 2003).

Kim et al. reported that, polymer modified systems could accommodate more damage prior to failure that that of unmodified systems. They indicated that mixtures containing PMB strongly exhibited less moisture damage (Kim et al., 1997).

Kumar et al. set out to examine the strength characteristics of polymer modified mixes. In their studies they concluded that there was an improvement in the moisture susceptibility characteristics of the polymer modified mixes (Kumar et al., 2006).

Stuart et al. reported that, mixtures with PMBs exhibited greater resistance to moisture damage than the mixtures with unmodified bitumen by providing increased adhesion to the aggregate and by creating a network within the bitumen (Stuart et al., 2001).

The objective of this study is to evaluate the effect of SBS and EVA based PMB on the stripping properties and moisture susceptibility characteristics of HMA containing different types of aggregate. For this purpose, the Nicholson Stripping Test (ASTM D 1664) and the Modified Lottman Test (AASHTO T 283) were performed on loose (uncompacted) mixtures and compacted samples respectively.

2. EXPERIMENTAL

2.1. Materials

The base bitumen with B50/70 penetration grade was procured from Aliaga/Izmir Oil Terminal of the Turkish Petroleum Refinery Corporation. In order to characterize the properties of the base bitumen, conventional test methods such as; penetration test, point test, ductility test, etc. were performed. These tests were conducted in conformity with the relevant test methods that are presented in Table 1.

Table 1. Properties of the base bitumen

Test	Specification	Results	Specification Limits
Penetration (25ºC; 0,1 mm)	ASTM D5 EN 1426	63	50-70
Softening Point (ºC)	ASTM D36 EN 1427	49	46-54
Viscosity at (135ºC)-Pa.s	ASTM D4402	0.51	-
Thin Film Oven Test (TFOT);(163ºC, 5 hr)	ASTM D1754 EN 12607-1		
Change of mass (%)		0.07	0,5 (max)
Retained penetration (%)	ASTM D5 EN 1426	51	50 (min)
Softening Point after TFOT (ºC)	ASTM D36 EN 1427	51	48 (min)
Ductility (25ºC), cm	ASTM D113	100	-
Specific Gravity	ASTM D70	1.030	-
Flash Point (ºC)	ASTM D92 EN 22592	+260	230 (min)

Two types of aggregates were utilized for producing the asphalt mixtures: Limestone aggregate (as coarse, fine and filler fraction) constitute the first type; whereas basalt aggregate (substituting the coarse fraction of limestone aggregate) constitute the second type aggregate. Both basalt and limestone aggregates were procured from Dere Beton/Izmir quarry. In order to find out the properties of the aggregate used in this study, specific gravity, Los Angeles abrasion resistance, sodium sulfate soundness, fine aggregate angularity and flat and elongated particles tests were conducted on both aggregate types. The results are presented in Table 2.

Table 2. The properties of limestone and basalt aggregates

Test	**Specification**	**Results**		**Specification Limits**
		Limestone	**Basalt**	
Specific Gravity (Coarse Agg.)	ASTM C 127			
Bulk		2.686	2.666	-
SSD		2.701	2.810	-
Apparent		2.727	2.706	-
Specific Gravity (Fine Agg.)	ASTM C 128			
Bulk		2.687	2.652	-
SSD		2.703	2.770	-
Apparent		2.732	2.688	-
Specific Gravity (Filler)		2.725	2.731	-
Los Angles Abrasion (%)	ASTM C 131	24.4	14.2	max 45
Flat and Elongated Particles (%)	ASTM D 4791	7.5	5.5	max 10
Sodium Sulfate Soundness (%)	ASTM C 88	1.47	2.6	max. 10 – 20
Fine Aggregate Angularity	ASTM C 1252	47.85	58.1	min. 40

Grading of aggregate was chosen in conformity with the Type 2 wearing course of Turkish Specifications. Table 3 and Table 4 present the final gradation chosen for limestone and basalt-limestone aggregate mixture.

Table 3. Gradation for limestone aggregate

Sieve Sizes or No.	**Specification**	**Gradation (%)**	**Specification Limits**
¾"	**ASTM C 136**	100	100
½"		90.5	83 – 100
⅜"		80.5	70 – 90
No. 4		47.3	40 – 55
No. 10		33	25 – 38
No. 40		13.5	10 – 20
No. 80		9	6 – 15
No. 200		5.3	4 – 10

Table 4. Gradation for basalt–limestone aggregate mixture

Test	**19 – 12.5 mm (basalt)**	**12.5 – 5 mm (basalt)**	**5 – 0 mm (limestone)**	**Combined Gradation (%)**	**Specification**	**Specification Limits**
Mixture Ratio (%)	15	45	40			
Sieve Sizes or No.					ASTM C 136	
¾"	100	100	100	100.0		100
½"	35.7	100	100	90.5		83 – 100
⅜"	2.5	89	100	80.5		70 – 90
No. 4	–	16	100	47.3		40 – 55
No. 10	–	–	81	33.0		25 – 38
No. 40	–	–	33	13.5		10 – 20
No. 80	–	–	22	9.0		6 – 15
No. 200	–	–	13	5.3		4 – 10

The elastomeric type polymer used was SBS Kraton D-1101, supplied by the Shell Chemicals Company. Kraton D-1101 is a linear SBS polymer in powder form that consists of different combinations made from blocks of polystyrene (31%) and polybutadiene of a very precise molecular weight (Shell Technical Bulletin, 1995). These blocks are either sequentially polymerized from styrene and butadiene and/or coupled to produce a mixture of these chained blocks.

The plastomeric type of polymer used was Evatane® 2805, supplied in pellet form by the Arkema Company. Evatane® 2805 which contains vinyl acetate content of 27-29% is a highly flexible plastomer designed for bitumen modification and especially for road paving. The properties of the Kraton D-1101 and Evatane® 2805 polymers are presented in Table 5.

Table 5. The properties of SBS Kraton D 1101 and Evatane 2805 polymer

Composition	**Specification**	**Kraton D 1101**	**Evatane® 2805**
Molecular Structure		Linear	Linear
Physical Properties			
Specific Gravity	ASTM D 792	0.94	
Tensile Strength at Break (MPa)	ASTM D 412	31.8	
Shore Hardness (A)	ASTM D 2240	71	
Physical Form	-	Pellet	Pellet
Melt Flow Rate	ASTM D 1238	< 1	5 – 8
Processing Temperature (°C)	-	150 – 170	65 – 80
Elongation at Break (%)	ASTM D 412	875	700 – 1000

2.2. Preparation of SBS and EVA Modified Bitumen

The SBS and EVA modified bitumen samples were prepared by means of a high and a low shear laboratory type mixer rotating at 1100 rpm and 125 rpm respectively. In preparation, the base bitumen was heated to fluid condition (180-185ºC), and poured into a 2000 ml spherical flask. The SBS and EVA polymers were then added slowly to the base bitumen.

The SBS Kraton D 1101 concentrations in the base bitumen were chosen as 2% to 6%. The utilization of this content is based on past research made by Isacsson and Lu. They stated that a significant improvement in the properties of base bitumen was observed when the SBS content was increased from 2% to 6% by weight (Lu and Isacsson, 1997). The Evatane® 2805 concentrations on the other hand were chosen as 3% to 7% according to the manufacturers.

On reaching 185ºC, the temperature was kept constant and the mixing process continued for two hours. The uniformity of dispersion of SBS and EVA in the base bitumen was confirmed by passing the mixture through an ASTM 100# sieve. After completion, the samples were removed from the flask and divided into small containers, covered with aluminum foil and stored for testing. The conventional properties of the SBS and EVA based PMB are presented in Table 6.

Table 6. Conventional properties of SBS Kraton D 1101 and Evatene® 2805 PMB

Property	Type	Content (%)						
		0	2	3	4	5	6	7
Penetration (1/10 mm)	SBS Kraton D 1101	63	61	51	49	48	48	-
Softening Point (°C)		49	50	54	57	67	69	-
Penetration Index (PI)		-0.92	-0.73	-0.16	0.35	2.18	2.46	-
Change of Mass (%)		0.07	0.06	0.06	0.07	0.07	0.07	-
Retained Penetration after TFOT (%)		51	41	31	24	21	21	-
Softening Point Difference After TFOT (°C)		2	4	4	2	3	2	-
Storage Stability (°C)		-	3	3	2	3	2	-
Penetration (1/10 mm)	Evatene® 2805	63	-	53	52	49	48	47
Softening Point (°C)		49	-	54	57	59	61	62
Penetration Index (PI)		-0.92	-	-0.13	0.49	0.79	1.14	1.24
Change of Mass (%)		0.07	-	0.04	0.06	0.05	0.07	0.06
Retained Penetration after TFOT (%)		51	-	30	31	32	33	34
Softening Point Difference After TFOT (°C)		2	-	6	6	5	4	5
Storage Stability (°C)		-	-	1	1	0	1	2

2.3. Test Methods

Following the determination of the properties of the materials used in this study and the preparation of the samples, the Nicholson Stripping Test and the Modified Lottman Test were conducted on loose mixtures and compacted samples respectively.

2.3.1. Nicholson Stripping Test

ASTM D1664 "Test Method for Coating and Stripping Test of Bitumen Aggregate Mixture" was used to evaluate the degree of stripping of asphalt mixtures. In this method, coarse aggregate (9.5mm-6.3mm) of both basalt and limestone was coated with PMB. The loose mixture was then immersed in distilled water for 24 hours and the degree of stripping was observed under water to visually estimate the total surface area of the aggregate on which bitumen coating remains.

2.3.2. AASHTO T 283: Standard Method of Test for Resistance of Compacted Hot Mix Asphalt (HMA) to Moisture-Induced Damage

The Modified Lottman Test was performed on the compacted samples including two types of aggregate (basalt-limestone mixture and limestone). The samples were prepared with the SBS Kraton D 1101 and the EVA Evatene® 2805 based PMB of different contents. In this study, the optimum bitumen content was determined as 4.73% (by weight of aggregate) for mixtures prepared with base bitumen, and 4.82% (by weight of aggregate) for mixtures prepared with SBS and EVA PMB

The aim of the modified Lottman Test is to evaluate susceptibility characteristics of the mixture to water damage. This test is performed by compacting specimens to an air void level of 7% ± 1.0. Three specimen are selected as dry (unconditioned) and tested without moisture conditioning; and three more are selected to be conditioned by saturating with water (55%–80% saturation level) followed by a freeze cycle (-18 °C for 16 h) and subsequently having a warm-water soaking cycle (60 °C water bath for 24 h). The specimens are tested for indirect tensile strength (ITS) by loading the specimens at a constant rate (50 mm/min vertical deformation at 25 °C) and the force required to break the specimen is measured.

Moisture susceptibility of the compacted specimens is evaluated by tensile strength ratio (TSR) which is calculated by following equation:

$$TSR = \frac{S_2}{S_1} \times 100$$

where; S_1 is the average indirect tensile stress of dry (unconditioned) specimens.
S_2 is the average indirect tensile stress of conditioned specimens.

In this study, specimens were sorted into two subsets (both dry and conditioned) of three specimens each so that average air voids (7%) of two subsets are equal. The design parameters related to Modified Lottman Test are presented in Table 7.

Table 7. Design parameters

Type of Bitumen	B50/70 penetration grade
Type of Aggregate	2 types aggregate – Basalt – Limestone Aggregate Mixture – Limestone Aggregate
Type of Additive and Content	2 types of additive – Elastomer (SBS Kraton D 1101) (2% - 6%) – Plastomer (EVA 2805) (3% - 7%)
Target Air Void Level (%)	7
Test Performed	Indirect Tensile Strength at 25 °C
Total Number of Specimen Tested	– 5 different SBS concentrations x 2 types of aggregate (basalt, limestone) x 2 (dry and cond.) x 3 replicates=60 – 5 different EVA concentrations x 2 types of aggregate (basalt, limestone) x 2 (dry and cond.) x 3 replicates=60 – Σ 120 specimens

3. RESULTS AND DISCUSSIONS

3.1. Nicholson Stripping Test (ASTM D 1664) Results

The visually inspected results of the prepared samples are presented in Table 8.

Table 8. Visual stripping resistance of basalt and limestone aggregate with PMB

Additive	Content (%)	Limestone	Basalt
SBS Kraton D 1101	0.0	50 – 55	35 – 40
	2.0	55 – 60	40 – 45
	3.0	70 – 75	55 – 60
	4.0	75 – 80	60 – 65
	5.0	80 – 85	70 – 75
	6.0	80 – 85	70 – 75
Evatene® 2805	0.0	50 – 55	35 – 40
	3.0	65 – 70	40 – 45
	4.0	70 – 75	40 – 45
	5.0	75 – 80	45 – 50
	6.0	75 – 80	45 – 50
	7.0	75 – 80	45 – 50

As presented in Table 8, among the unmodified samples (with no polymer addition), the level of coating related to limestone and basalt aggregate lies between 50-55 and 35-40 respectively. This indicates that basalt aggregate exhibits more stripping potential compared to limestone aggregate. The reason for this pattern is the hydrophilic (attracting water) character of basalt type aggregate that has a higher affinity to form hydrogen boding with water and consequently promotes stripping.

The resistance to stripping increases with increasing polymer content for both aggregate types as presented in Table 8. Besides, no significant stripping variation is observed in the values on reaching the SBS and EVA polymer contents of 5%.

Among the samples prepared with basalt aggregate, a clear distinction regarding to the degree of stripping is observed between SBS and EVA modified samples as seen in Table 8. Based on the basalt aggregate mixture prepared with 4% polymer content, the mixture involving EVA polymer exhibits more moisture susceptibility compared to the mixture involving SBS polymer.

The samples were also examined at room temperature under Leica S8AP0 Stereo microscope after Nicholson Stripping Test. Images were taken by a 7.2 Mp Leica DFC 320 color camera (fitted in line with the optic axis of the microscope by means of attachment). The camera digitizes the image and stores the data as an image file in the permanent memory of the workstation. Fig. 1 and Fig. 2 present the examples of the samples captured by using digital camera.

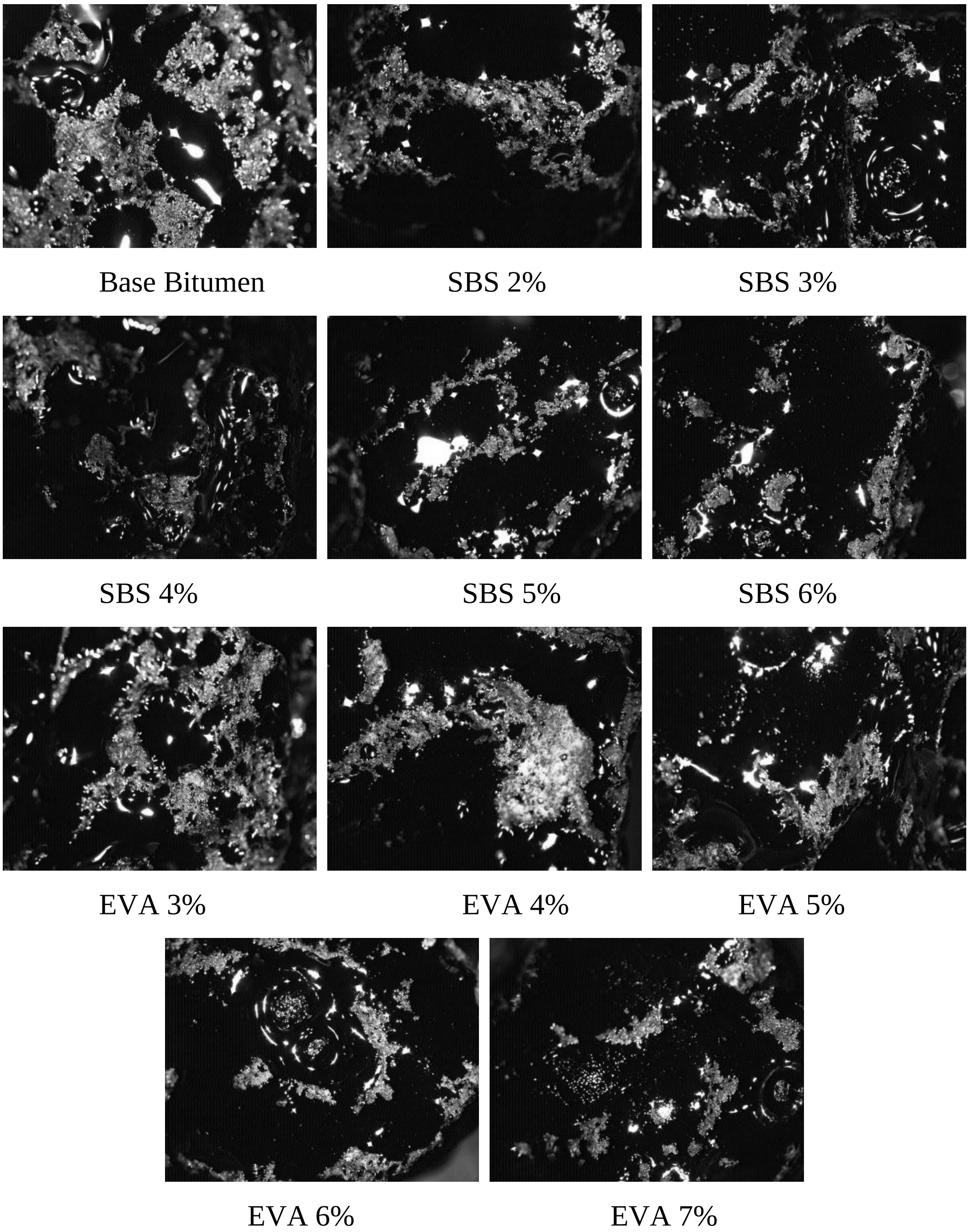
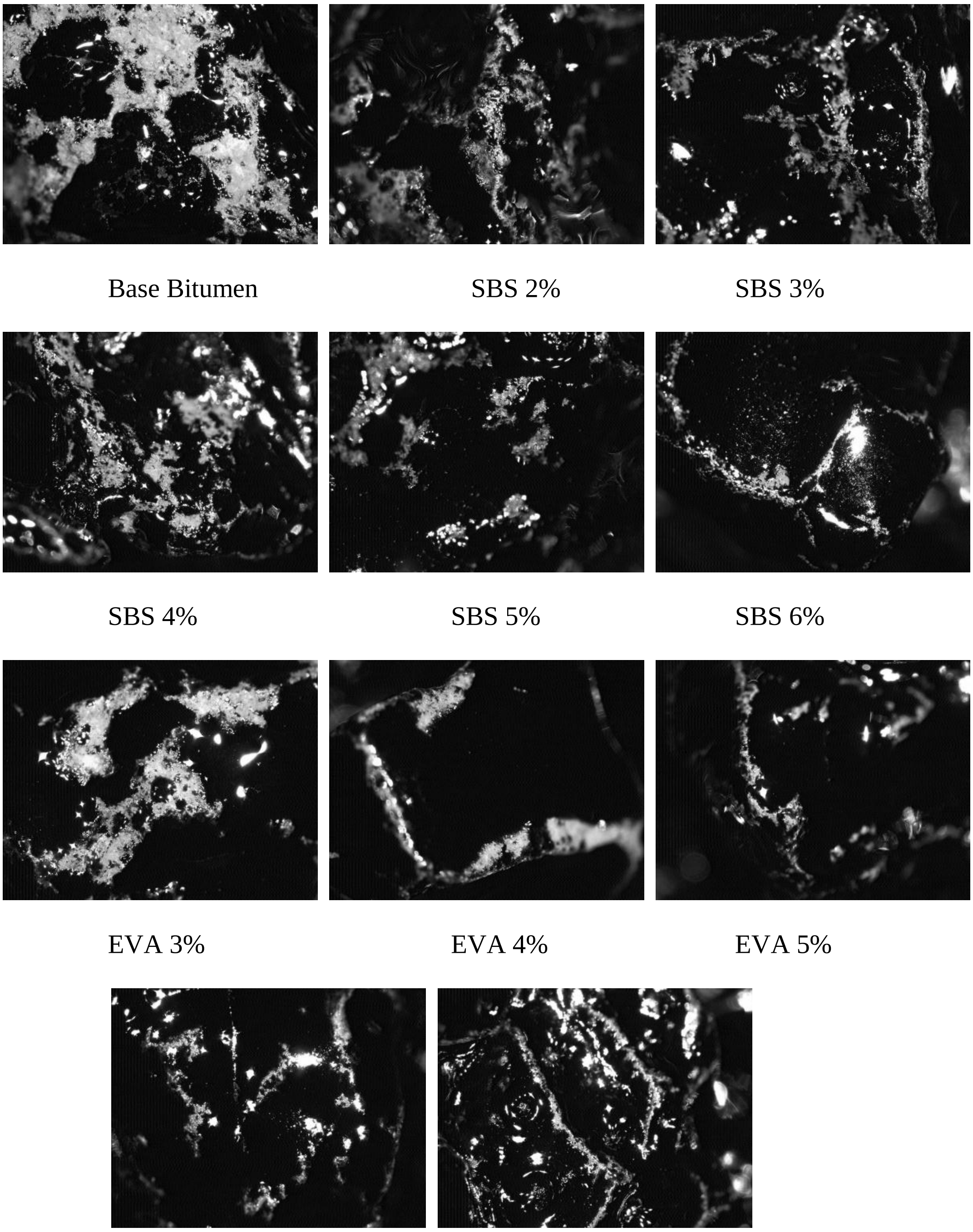


Figure 1. Basalt aggregate samples captured by Stereo microscope

A distinction can be made between the basalt and limestone aggregate for all samples. This indicates that the adhesion between aggregate and asphalt in HMA prepared using limestone aggregate is higher than that of mixes prepared using basalt aggregate. In other words, the HMA prepared using limestone aggregate have higher resistance to stripping since the bond strength between asphalt and limestone aggregate is stronger than that between asphalt and basalt aggregate.



Base Bitumen SBS 2% SBS 3%

SBS 4% SBS 5% SBS 6%

EVA 3% EVA 4% EVA 5%

EVA 6% EVA 7%

Figure 2. Limestone aggregate samples captured by Stereo microscope

As indicated in Figure 1 and Figure 2, the images show a clear variation in the level of coating on basalt and limestone aggregate as the polymer content increases. Besides, based on the same type of aggregate and polymer content, the difference in the level of coating can be observed between the SBS and EVA polymer. The mixture with EVA polymer exhibits more stripping potential compared to the mixture with SBS polymer.

In the light of findings, it is possible to consider that for evaluating the stripping potential of the aggregates, same trends are achieved from captured images as well as from Nicholson Stripping Test.

3.2. Modified Lottman Test (AASHTO T 283) Results

The ITS test results of specimens involving SBS and EVA polymer are given in Table 9.

Table 9. Indirect tensile strength test results of the compacted samples

Additive	Content (%)	Limestone Aggregate		Basalt – Limestone Aggregate	
		Unconditioned (kPa)	Conditioned (kPa)	Unconditioned (kPa)	Conditioned (kPa)
Kraton D 1101	0.0	1118.160	995.375	1164.815	1024.039
	2.0	1363.124	1266.343	1399.579	1287.613
	3.0	1420.984	1340.130	1498.456	1401.656
	4.0	1479.322	1412.158	1593.581	1508.324
	5.0	1708.318	1643.061	1902.490	1814.976
	6.0	1531.799	1478.952	1650.459	1577.839
Evatene® 2805	0.0	1118.160	995.375	1164.815	1024.039
	3.0	1318.994	1228.116	1417.053	1301.422
	4.0	1372.931	1296.047	1482.241	1379.818
	5.0	1429.810	1360.035	1556.479	1461.845
	6.0	1492.572	1425.854	1614.604	1523.541
	7.0	1529.155	1462.172	1659.937	1568.475

In order to evaluate the effect of SBS and EVA type polymer on the moisture susceptibility characteristics of samples prepared with different types of aggregate (basalt-limestone mixture and limestone), the additive content is plotted against the values of the ITS for both control (dry) and conditioned specimens. The TSR is also introduced in the same figure based on each additive content. The results are presented in Figure 3, and Figure 4.

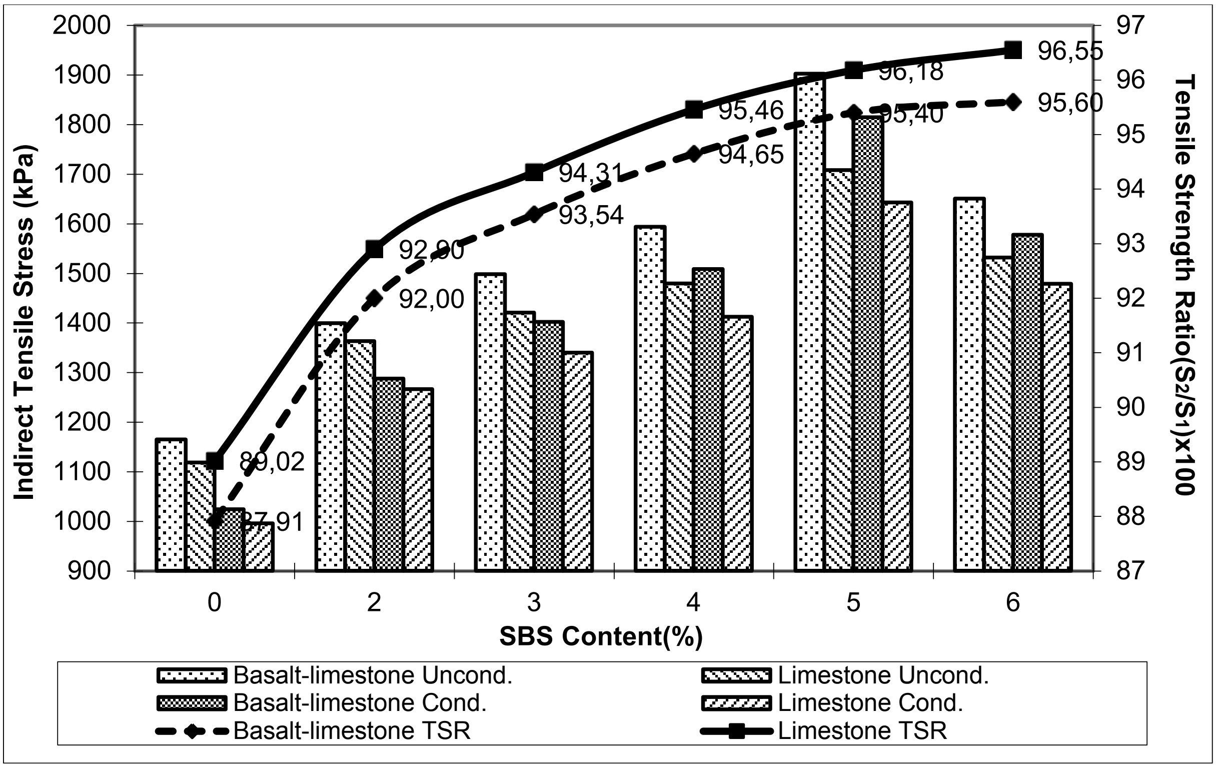


Figure 3. ITS and TSR results for each types aggregates with SBS PMB

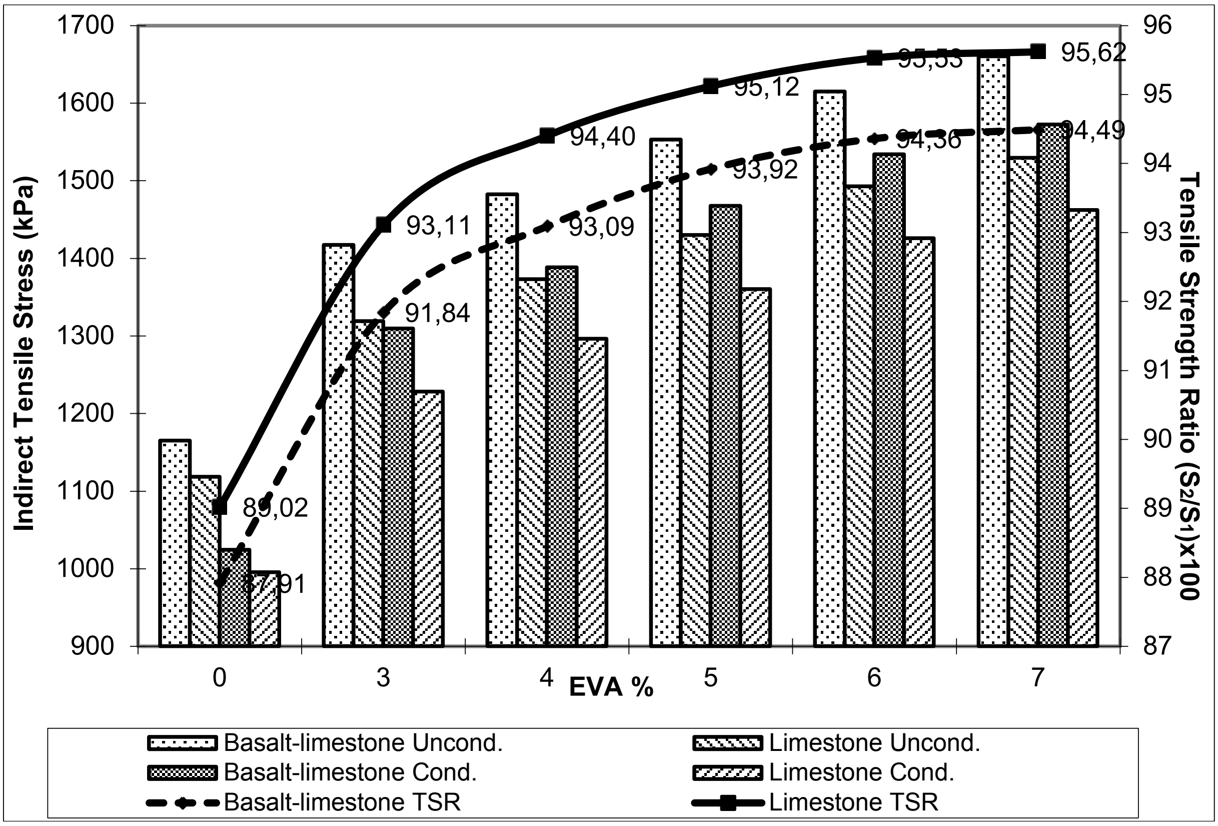


Figure 4. ITS and TSR results for each types aggregates with EVA PMB

As depicted in Figure 3, Figure 4 and Table 9, for all samples involving SBS and EVA polymer, the ITS of the samples prepared with basalt-limestone aggregate is greater than the ITS of the samples prepared with limestone aggregate. This difference may be attributed to the rigidity of the basalt aggregate. Besides, the ITS of the samples containing polymer additive is greater than the ITS of the unmodified mixtures. This indicates that the mixtures containing additives have higher values of tensile strength at failure under static loading. The greater the tensile strength of the modified mixtures as compared to unmodified mixture also indicates greater cohesive strength of the SBS and EVA modified mixtures.

The ITS test results are also used to evaluate the cracking properties of the pavement (Tayfur et al., 2007). Numerous researches have shown that higher tensile strength values correspond to higher cracking resistance (Huang et al., 2003). As presented in Fig. 3, 4 and Table 9; polymer modified mixtures with higher ITS values appear to be capable of withstanding larger tensile strains prior to cracking compared to unmodified mixtures. In addition, among the samples prepared with the same type of aggregate, the samples prepared SBS PMB exhibit greater resistance to cracking compared to EVA PMB samples.

As presented in Fig. 3 and 4, for both types of aggregate as the SBS and the EVA polymer content increases, the TSR values increase as well. This indicates that the resistance of asphalt mixes to the detrimental effect of water increases with the increase in polymer content. However, no significant change in the values of TSR is observed on reaching the SBS and EVA content of 5% and 6% respectively.

For all SBS and EVA polymer contents, the TSR of basalt-limestone aggregate is smaller than the TSR values related to limestone illustrated in Fig. 3 and 4. This indicates that the introduction of basalt aggregate into the limestone increases the susceptibility of the mixture to moisture damage.

As seen in Figure 3 and Figure 4, for both types of aggregate prepared with the same polymer content, the TSR of mixtures prepared with the SBS PMB is greater than the TSR of mixtures prepared with the EVA PMB. This indicates that mixtures including the EVA PMB exhibit more stripping potential compared to the SBS PMB.

4. CONCLUSION AND RECOMMENDATIONS

Moisture damage in asphalt mixtures is a complex mechanism and has many interacting factors such as mixture design, proper construction, traffic and environment. Among these factors, the properties of the additives gained wider attention and must be investigated carefully. Therefore, the main objective of the study is to evaluate moisture susceptibility characteristics HMA in terms of additives such as plastomeric and elastomeric type polymers. The following conclusions can be drawn.

Mixtures prepared with SBS and EVA PMB display reduced stripping potential and moisture susceptibility than mixtures prepared with base bitumen for all types of aggregate (basalt-limestone aggregate mixture and limestone aggregate). As a consequence, it can be concluded that, polymer modified bitumen provides increased adhesion to the aggregate and creates a network structure within the base bitumen.

In the light of the findings from laboratory investigations, it is possible to consider that SBS polymer addition has shown a greater degree of improvement in resistance of asphalt mixture to the detrimental effect of water compared to EVA polymer addition.

A clear distinction between the mixtures prepared with the same polymer type indicates that at a given polymer content such as 3%, the mixtures prepared with basalt – limestone aggregate exhibit more moisture susceptibility than the mixture prepared with limestone aggregate. This difference may be attributed to the formation of a weak bond between the basalt aggregate and the bitumen both of which are acidic in character.

Moisture damage of asphalt mixtures is usually estimated visually or with the help of mechanical tests. However, with the introduction of image analysis techniques and software programs, the degree of stripping can be carefully estimated from microscopically captured images.

The conclusion of this study covers the utilization of one type of elastomer, plastomer and penetration grade bitumen. More research should be carried out using different kinds of polymers as well as the base bitumen obtained from different crudes.

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