ISSN NO. 2320-5407

Journal homepage: http://www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH

RESEARCH ARTICLE

Influence of Styrene –Butadiene - Styrene on Hot Mix Asphalt Moisture Damage Resistance

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Manuscript Info

Manuscript History:

Received: 15 September 2015
Final Accepted: 15 October 2015
Published Online: November 2015

Key words:

Hot mix asphalt , Marshall properties , Moisture damage, SBS.

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Abstract

Moisture damage in hot mix asphalt is defined as the loss of strength and stability caused by the active presence of moisture. The most common technique to mitigate moisture damage is using modifiers with the asphalt cement and the aggregate. Various additives and modifiers are used to enhance the performance of asphalt mixtures. However, some of these additives/modifiers may affect the moisture susceptibility of hot mix asphalt. The objective of this study was to investigate the influence of Styrene –Butadiene - Styrene (SBS)on the moisture sensitivity of modified asphalt mixtures . The seven SBS percentages were selected (0.5, 1.0, 1.5, 2.0, 2.5, 3.0 and 3.5) % by the weight of asphalt. The laboratory tests includes: Marshall Test, indirect tensile strength test, and the index of retained strength test. The test results have exhibited that, the asphalt mixtures modified by SBS have shown improvement of Marshall Properties, and increasing the moisture damage resistance. The modified hot mix asphalt contain 2.5% SBS by the weight of asphalt has good Marshall properties and moisture damage resistance.

1-INTRODUCTION

The durability of the asphalt mixtures is mainly affected by environmental factors such as temperature, water and air. Water or moisture causes the loss of adhesive or bonding between the aggregate and asphalt. This failure phenomenon is referred to as stripping in the asphalt concrete pavements. Water may attack the aggregate-asphalt interface and cause the weakness of this interface **(Gorkem and Sengoz , 2009)**. Many variables lead to the occurrence of moisture damage in asphalt paving mixtures. Some of these variables are related to the properties of the asphalt and aggregate forming the asphalt mixtures. Moreover, mix design procedure, environmental factors (air temperature , water and aging) , traffic conditions and additives properties are considered as other variables affecting asphalt paving mixtures **(Behiry, 2013)** . The author reported that controlling the failure due to moisture damage could be recommended to adopt the utilization of ant- stripping additives. The anti-stripping additives can be active in increasing the physical and chemical bonding between asphalt and aggregate .These ant- stripping additives may include the traditional several polymer types. These polymers play an important role in improving the physical properties of asphalt cement such as softening point, ductility and viscosity. This improvement in asphalt properties will reflect on the aggregate and asphalt interface and resistance of asphalt mixture to moisture damage will increase. Styrene- Butadiene- Styrene (SBS) is one of most polymers that were used for modifying asphalt mixtures and improved its resistance for moisture damage **(Ozen, 2011)**.

There are many laboratory tests to evaluate the moisture damage of asphalt paving materials under various conditions **(Caro et al., 2008)**. The laboratory tests can be divided into three groups: tests on compacted samples such as the Marshall stability test, tests on loose mixture samples such as the water immersion method and tests on the components of the asphalt mixture such as the dynamic Wilhelm plate method **(Cho and Bahia 2007).** On the other hand the tensile strength ratio (TSR) test is more suitable to measure the moisture damage of hot mix asphalt **(Breakah, 2009)**.

The motivation behind this study is to investigate influence of SBS polymer on the moisture damage resistance for asphalt mixtures. The SBS modifier was blended with asphalt cement by various percentages of (0.5, 1, 1.5, 2, 2.5, 3, and 3.5%) by the asphalt weight. The modified asphalt mixture properties (Marshall, indirect tensile and index of retained strength) have been evaluated to choose optimum SBS percentage.

2-LITERATURE REVIEW

The additives or modifier such as the polymers are common used to modify the asphalt cement properties and as a result the asphalt mixture performance will improve. There are several types of polymers such as : plastic, elastomers, fibers, and coatings **(Isacsson et.al, 1995)** . Among different polymer types, the elastomer styrene-butadiene- styrene (SBS) is most widely used as a modifier. It is identified that SBS can improve the mechanical properties of mixtures such as fatigue **(Cortize et.al, 2004)**, permanent deformation **(Tayfur et.al, 2007)** and **(Vlachovicova et.al, 2007)**, low temperature cracking **(Isacsson et.al, 1997)**, and resistance to moisture damage **(Won MC, et.al,1994).**

Won Mc and Homk, 1994 investigated the properties of polymer modified bitumen (PMB) with two additives types. They concluded the using of SBS as additive in asphalt mixtures will improve moisture damage compared with mixtures modified with ethylene-vinyl acetate (EVA) polymer.

Lu X, Isacsson U, 1997 tested the rheological characterization of SBS copolymer modified bitumen. They found the a significant improvement in the asphalt cement properties was observed when SBS percentage increased from 2 to 6 % by weight of asphalt weight.

Stuart, et.al, 2001 worked on the study of influence of SBS on adhesion force for aggregate –asphalt interface. They found that mixtures modified by SBS polymer exhibited high resistance to moisture damage than the control mixture. This resistance is due to increased adhesion force and creating more bonding between aggregate and asphalt.

Awanti, 2008 evaluated asphalt mixtures modified by SBS polymer with various percentages up to 5 % by weight of mixture. Test results indicated that the moisture susceptibility of modified mixes is low as a compared with control mixture and Marshall properties and temperature susceptibly of SBS modified mixtures have improved when they were compared with control one.

Baha and Mehmet, 2009 investigated the effect of combined SBS and hydrated lime on the moisture damage sensitivity of asphalt mixtures. They founded that SBS as a modifier will increase the resistance of asphalt mixture to moisture damage.

Al-Hadidy et.al, 2010 studied the performance of modified asphalt binder used in the flexible pavement by using a mechanistic design method to predict the service life of pavement constructed from modified surface layer. They have concluded that the pavement constructed from SBS modified mixture in surface layer pavement gave beneficial in saving the construction materials.

The effect of SBS polymer as additive on the mechanical behaviour of hot mix asphalt has been investigated by **(Albayati, et.al, 2011).** The experimental results have been indicated the fatigue and permanent deformation improved by using of SBS in modified asphalt mixture with percentage of 3 % by weight of asphalt.

Imad Al-Qadi, 2014 investigate the effect of various additives on moisture susceptibility of asphalt mixtures. The additives were liquid anti-strip (LAS), styrene butadiene styrene (SBS), polyphosphoric acid (PPA). They founded that SBS additive was best one in improving the moisture damage resistance.

3-MATERAIL PROPERTIES

3-1 Asphalt Cement

Asphalt cement (40-50) penetration grade obtained from Nasiriyah refinery in Iraq south. This asphalt was used on highways which have been carrying high traffic loading and hot climate in Iraq. The physical properties of asphalt cement and general Iraq specifications **(SCRB/ R9, 2003)** are listed in Table 1.

3-2 Aggregate

Coarse and fine aggregate obtained from Al- Najaf quarries south Baghdad city were used in preparing modified and unmodified mixtures. The physical properties of aggregate are shown in Table2. Filler is a non-plastic material passing sieve No.200 (0.075mm), usually used to improve mixture properties. The filler used in this work is Portland cement brought from the Kufa cement factory in Al-Najaf governorate. The physical properties of the used filler are presented in Table 3. The aggregate and filler were sieved and recombined to meet the requirements of wearing course gradation Type III A according to SCRB specifications **(SCRB, 2003)** as reported in Table 4.

3-3 Styrene-Butadiene-Styrene (SBS)

SBS is a thermoplastic polymer that improves the overall performance of asphalt pavement by increasing the stability, elasticity, and stiffness of asphalt binders. SBS softens under high temperature; therefore, it can be easily added and mixed with asphalt binder. The effect of SBS-modified asphalts on moisture sensitivity remains undetermined. It has not yet been confirmed whether SBS modification increases or decreases the moisture damage potential **(Tarefder and Zaman 2010)**. Figure 1 illustrates SBS modifier used in preparing asphalt mixtures

Figure 1 : SBS modifier used

The SBS polymer, used in this study, brought from the Kraton Company in France. The SBS polymer is added to asphalt cement with a percentage of (0.5, 1, 1.5, 2, 2.5, 3, and 3.5%) by the weight of asphalt and blended together by using a mixer. Table 5 presents the SBS properties.

4. LABORATORY TESTS

In this study, a detailed laboratory investigation was undertaken. The laboratory investigation focused on the influence of SBS modifier when added to asphalt mixes to evaluate moisture-susceptible of hot mix asphalt. The experimental work includes: Marshall mix design, tensile strength ratio test and index of retained strength test.

4-1 Marshall Mix Design

The specimens were prepared according to Marshall mix design procedure in accordance with standardized method ASTM D 1559 **(ASTM, 2009)**. The asphalt cement and aggregate were mixed at 155^{o}C. Marshall specimens were compacted using the standard Marshall hummer with 75 blows on each face of the specimen at compaction temperature of 130 ^{o}C. The specimens were immersed in a water bath at 60°C for 30±5 minutes. Specimens were removed from the water bath and quickly placed in the Marshall machine. The Marshall apparatus deformed the specimen at a constant rate of 50.8 mm per minute. Stability was identified as the maximum load sustained by the sample. Flow was the deformation at maximum load. Also, the voids in total mix (VTM) percentages were determined for control and modified asphalt mixtures. The optimum asphalt contents for all modified and control mixtures were determined using the procedure indicated in the Asphalt Institute Manual (MS-2) **(Asphalt Institute, 1993).** Table 6 summaries Marshall properties of the various modified and control asphalt mixture.

4-2 Tensile Strength Ratio Test

The moisture damage of hot mix asphalt was evaluated by the indirect tensile test (ITS) was performed in accordance with AASHTO T283 **(AASHTO, 2007)**. In the indirect tensile strength test, Marshall specimens are subjected to compressive loads which act along to vertical diametric plane at rate of 50 mm/min until specimen reaches to failure. In this test, six specimens are divided into two groups each group consists of three specimens, the first one represent control samples (unconditional specimens) which they were tested at 25°C temperature. The second group (conditional samples) were submerged in water at 60°C for 24 hr period, and then tested at 25°C. All specimens were compacted to 7% voids in total mix by using Marshall hammer **(ASTM, 2009)**. The indirect tensile strength of condition and unconditioned specimens is calculating from equation 1 as follows:

$$ITS=2000P/\pi.\ h\ .D \qquad \dots (1)$$

Where ITS is indirect tensile strength (MPa) , P is the maxim load at failure (N) , h is specimen thickness (mm), D is specimen diameter. Moisture susceptibility of the compacted Marshall specimen is obtained using equation 2:

$$TSR= ITS_{con}/ ITS_{uncon} \qquad \dots (2)$$

Where TSR is tensile strength ratio (%), ITS_{con} is average indirect tensile strength for conditioned sample (MPa), ITS_{uncon} is average indirect tensile strength for unconditioned sample(MPa). The minimum percent of tensile strength ration is 80 % **(AASHTO, 2007)**. Table 7 reports the indirect tensile strength for conditioned sample (ITS_{con}) ,indirect tensile strength for unconditioned sample (ITS_{uncon})and tensile strength ratio

4-3 Index of Retained Strength Test

In addition to TSR test the index of retained strength (IRS) test was conducted on various modified and control asphalt mixtures at optimum asphalt contents to test the moisture damage of theses mixes in accordance with ASTM D 1075**(ASTM, 2009)**. IRS test is only durability test required by SCRB specification to be performed on the asphalt mixes used in construction of surface course **(SCRB, 2003)**. The purpose of (IRS) test is to measure the loss of strength and adhesions between aggregate and asphalt caused by the active presence of moisture and it is performed on the compacted cylindrical specimens with dimensions of 101.6 mm in diameter and height . The index of retained strength (IRS) can be determined from equation 3:

$$IRS=S_2/S_1 \qquad \dots (3)$$

IRS is index of retained strength (%), S_2 is average compressive strength of immersion specimen (MPa), and S_1 is average compressive strength of dry specimen (MPa).

The standard Iraqi specifications **(SCRB-R9, 2003)** require the minimum IRS value of 70%. Table 8 presents the compressive strength of dry sample and compressive strength of immersion sample.

5. TEST RESULTS AND DISCUSSION

5-1 Influence of SBS on Marshall Properties

From Table 6 it can be observed that the increasing the SBS percentages in modified mixtures cause the increasing the Marshall stability values and air voids, and decreasing of flow values. This means the SBS with high percentages render the modified asphalt mixtures exhibit high resistance to traffic loading with good stiffness and low workability. In addition the upper percentage of SBS is 2.5 % by weight of asphalt content while the using higher SBS percentages (3 and 3.5 %) by weight of asphalt give the Marshall flow values and air voids percentages of modified mixtures don't fulfill SCRB requirements **(SCRB,2003)** for Marshall flow and air voids only.

5-2 Influence of SBS on Tensile Strength Ratio

Tensile Strength Ratio (TSR) has been used for predicting moisture susceptibility of mixtures. The recommended limit of (80 %) for tensile strength ratio (TSR) is used to distinguish between moisture susceptible mixture and moisture resistance mixtures (**AASHTO T-283, 2007**). In order to evaluate the influence of SBS on the moisture damage resistance .Figure 2 presents the relation between the TSR and SBS percentage. The results show that, the ITS for asphalt mixtures modified by SBS at different content are greater than ITS for control mixture. As shown in figure 2 , the TSR values increase with increase SBS content up to 2.5% and TSR values slightly decrease for mixtures contain SBS in for (3.0 and 3.5%) with TSR of 79.25 and 77.31% respectively . This means the high percentages of SBS (3.0 and 3.5%) reduces the moisture resistance of modified mixture. The increasing in TSR values refers that the resistance of asphalt mixtures to moisture damage increase as well as the SBS content increase and exhibited more stripping resistance than control mixture.

5-3 Influence of SBS on Index of Retained Strength

The index of retained strength (IRS) is used to predict the moisture susceptibility of the mixtures. Figure 3 illustrates IRS values for modified and control mixtures. It is seen that the IRS values for modified mixtures increases with increasing SBS percentages from 0.50 % to 3.5% by weight of asphalt in mixture. This means that modified asphalt mixtures exhibit high resistance to moisture damage and this resistance increases with the increasing of SBS percentages. The other conclusion from Table 8 and Figure 3 that IRS value of 3.5% SBS modified mixtures is approximately 19% more than control ones.

6. CONCLUSIONS

The main objective of this study was to evaluate the influence of various SBS polymer percentages on moisture damage resistance of modified asphalt mixtures. Based on the laboratory test results, the following conclusions were drawn:

1. In the Marshall test results, Marshall stability values and voids in total mix percentages increased and Marshall flow values decreased with the increasing of SBS polymer percentages from 0.50 to 3.5 % by weight of asphalt. The maximum percentage of SBS polymer in modified mixtures that fulfilled SCRB specifications for Marshall stability , flow and air void was 2.5 % .
2. The tensile strength ratios increased by 9 % for modified asphalt mixtures contained 2.5% SBS polymer when compared with control mix. It is not recommended to increase the SBS percentage in modified asphalt mixtures more than 2.5 % because higher percentages cause reduction in the resistance of asphalt mixture to moisture damage.
3. Index of retained strength values increase with the increasing of SBS percentage from 0.5 % to 3.5 % by weight of asphalt. Also, IRS values of SBS mixtures contained 2.5% is 17% more than control ones. According to test results this would further imply that modified asphalt mixtures with 2.5 % SBS appeared to be more moisture damage resistance.

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Table1: Asphalt cement properties

Property	ASTM Designation	Test Results	Requirements Penetration –Graded Asphalt Cement (40/50)
1.Penetration at 25 ^{o}C , (0.10mm)	D5	48	40-50
2. Ductility at 25 ^{o}C , (cm)	D113	110	>100
3.Specific gravity at 25 ^{o}C	D70	1.03	------
4.Flash point ,(^{o}C)	D92	275	>232
5.Solubility in trichloroethylene		99.37	>99
6.Residue from thin –film oven test	D1754		
- Retained penetration , % of original	D5	68	>55
-Ductility at 25 ^{o}C, (cm)	D113	57	>25

Table 2: Physical properties of aggregates

Property	ASTM Designation	Test results	SCRB specifications (SCRB/R9,2003)
Coarse aggregate			
• Bulk specific gravity	C 127	2.614	….
• Apparent specific gravity	C 127	2.686	….
• Percent wear by Los Angeles abrasion , %	C131	22.7	30 Max.
• Soundness loss by sodium sulfate solution,%	C88	3.4	12 Max.
• Degree of crushing, %		98	90 Min.
Fine aggregate			
• Bulk specific gravity	C127	2.664	….
• Apparent specific gravity	C127	2.696	….
• Sand equivalent, %	D2419	57	45 Min.

Table3: Physical properties of used filler

Property	Test method	Result
%passing sieve No.200	———	96
Specific gravity	ASTM C 128	3.13
Fineness(cm^2/gm)	———	3123

Table4: Aggregate gradation

Sieve size(mm)	19	12.5	9.5	4.75	2.36	0.3	0.075
Percent passing (SCRB)	100	90-100	76-90	44-74	28-58	5-21	4-10
Mid –limits percent of passing	100	95	83	59	43	13	7

Table5: Physical and mechanical properties of SBS

Properties	Value
Density(Kg/m^3)	1247
Melting point	197
Apparent	yellow

Table6: Properties of asphalt mixtures

Mixture type	Marshall stability (kN)	Marshall flow(mm)	Bulk density, (gm/cm^3)	Voids in total mix (%)	Optimum asphalt content(%)
Control mix	11.2	3.3	2.322	4.1	5.12
0.5%SBS	12.5	3.3	2.303	4.2	5.10
1.0%SBS	13.9	3.2	2.276	4.4	5.06
1.5%SBS	14.2	3.1	2.278	4.4	5.06
2.0%SBS	15.3	2.8	2.284	4.5	5.02
2.5%SBS	16.4	2.2	2.266	4.7	4.96
3.0%SBS	18.8	1.6	2.252	5.4	4.72
3.5%SBS	20.7	1.4	2.213	5.6	4.82
SCRB /R9 requirements (SCRB,2003)	Min 8 kN	2-4 mm	-------	3-5%	4-6%

Table7: Indirect tensile strength and tensile strength ratio results

Mixture type	ITS_{uncon} Mpa	ITS_{con} Mpa	%TSR
Control mix	1.192	0.972	81.58
0.5%SBS	1.244	1.041	83.72
1.0%SBS	1.362	1.147	84.21
1.5%SBS	1.379	1.185	85.92
2.0%SBS	1.480	1.288	87.02
2.5%SBS	1.552	1.375	88.63
3.0%SBS	1.603	1.270	79.25
3.5%SBS	1.632	1.262	77.31

Table8: Index of retained strength values

Mixture type	S_1, Mpa	S_2, Mpa	IRS (%)
Control mix	1.904	1.390	73.02
0.5%SBS	1.933	1.458	75.43
1.0%SBS	2.042	1.591	77.93
1.5%SBS	2.157	1.692	78.43
2.0%SBS	2.389	1.886	78.93
2.5%SBS	2.422	2.069	85.43
3.0%SBS	2.483	2.140	86.21
3.5%SBS	2.511	2.179	86.79

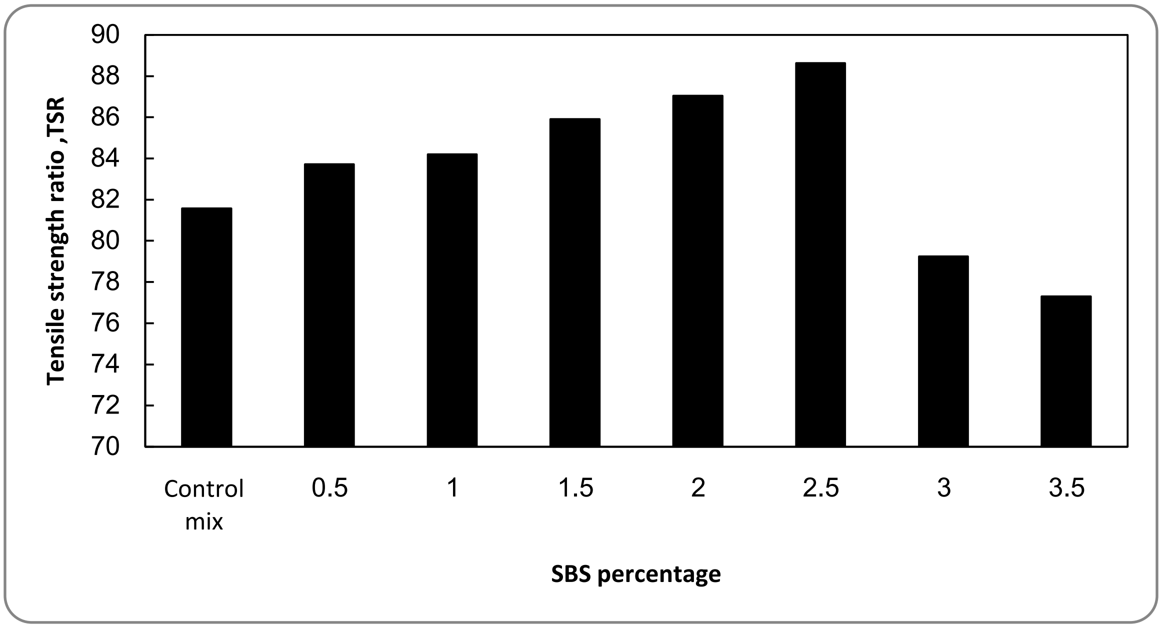

Figure2: The influence of SBS percentage on the TSR values

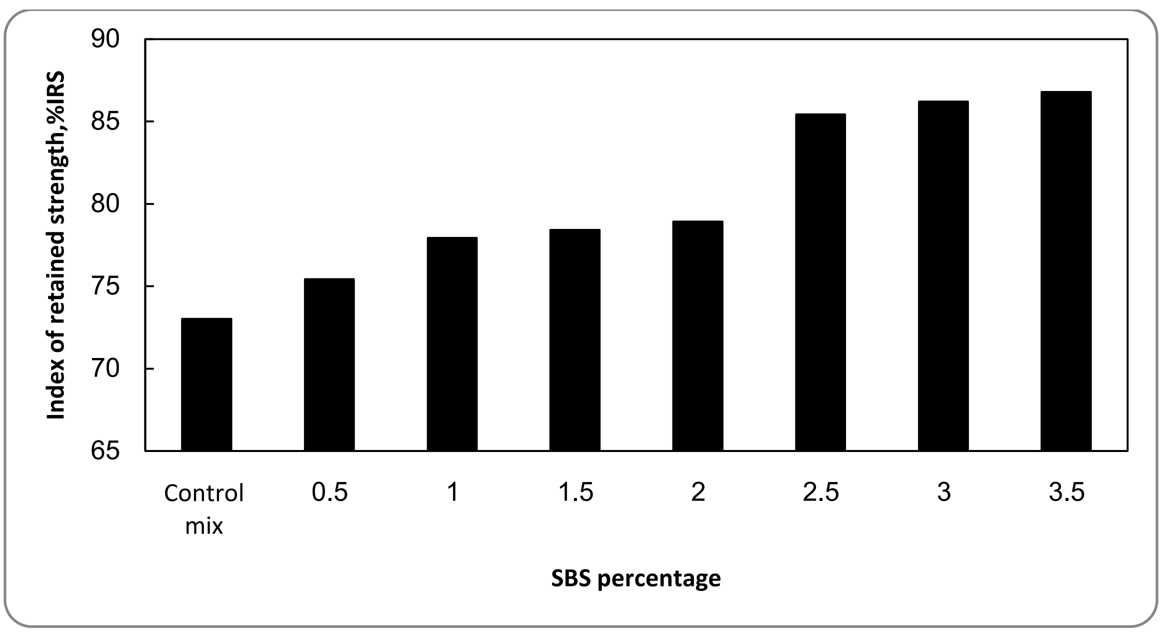

Figure3: Influence of SBS percentage on the IRS values