The Effect of Styrene-Butadiene- Styrene on Moisture Damage Resistance of Asphalt Mixtures

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Abstract

The moisture damage is one of the main failure modes affecting on the flexible pavement performance. The stripping action of water helping to reduce the bonding strength between the asphalt binder and the aggregate particles. The moisture damage resistance depends on many factors: asphalt binder, aggregate type, and mineral filler. This study has been made to evaluate the effect of SBS on the moisture sensitivity. The asphalt mixtures are divided into two types: the unmodified, and the modified. The SBS content was (0.5, 1.0, 1.5, 2.0, 2.5, 3.0.3.5, 4.0) % by the weight of asphalt. The performance tests include: Marshall Test, Indirect Tensile Strength Ratio test, and the Index of Retained Strength test. The tests results show that the asphalt mixtures modified by SBS have shown a developed in the Marshall properties, and increasing the moisture damage resistance. However, the using of (3% SBS) by the weight of asphalt has the best effect on the Marshall properties, and on the moisture damage resistance, which increase the pavement performance against the environmental effects.
Key Words: Asphalt mixtures, Moisture damage, SBS.

الخلاصة

يعتبر الاثر الاتلافي للماء من اهم مشاكل الفشل التي تؤثر على كفاءة الطرق الاسفلتية بسبب اثر الانفصال للماء الذي يعمل على تقليل قوة الربط بين مادة الاسفلت والركام. وتعتمد مقاومة الخلطات الاسفلتية على عدده عوامل منها: الاسفلت، نوع الركام، والمادة المالئة. ان الغرض من هذه الدراسة هو لمعرفة تأثير مادة الـ **SBS** على مقاومة الخلطات الاسفلتية للماء. حيث تم استخدام نوعين من الخلطات الإسفلتية(الخلطات الغير معدلة، والخلطات المعدلة)،وكانت نسبة الـ**SBS** المستخدمة(٠,٥ ، ١،٠،١،٥،٢،٠،٢،٥،٣،٠،٣،٥،٤،٠) من وزن الاسفلت الكلي. واشتملت الفحوصات على فحوصات مارشال القياسية، فحص الشد الغير مباشر ، وفحص مقاومة الانضغاط المسترجعة. وتشير نتائج هذه الفحوصات الي ان استخدام (٣,٠% من مادة الـ **SBS**) لها تأثير جيد على خواص الخلطة الاسفلتية، اضافة الي تحسين مقاومة الخلطة لتأثير الماء وهذا يؤدي الي زيادة كفاءة الطريق .
الكلمات المفتاحية: الخلطات الاسفلتية، الاثر الاتلافي للماء، لدائن الـ**SBS**.

1-Introdcution

Moisture damage is the result of moisture interaction with asphalt binder aggregate adhesion within asphalt mixture. This interaction can cause a reduction of adhesion between asphalt binder and aggregate, called stripping, which can lead to various forms of asphalt mixture distress including rutting and fatigue cracking. The effects of water when penetrated into the mixture represent on reduce mechanical reaction between asphalt binder and aggregate surface. There are many factors effecting moisture damage, asphalt binder represent the first major factor, with increasing asphalt viscosity, moisture damage on asphalt mixtures reduce, because high viscosity means higher concentrations of asphaltene (i.e. large polar molecules), which can create greater adhesion ,and molecular orientation adhesion. The second factor is the aggregate which effects on the moisture damage resistance, depending on the type of aggregate and its nature, moisture damage also affect. In addition to these factors, also air voids effect on moisture damage, with increasing air voids, the moisture damage increase, climate and traffic can also affect on moisture damage resistance.

To reduce the effect of moisture damage on asphalt mixture and developed it resistance, many methods are used for this reason. The anti strip additives have been used to reduce moisture effect and improve resistance, one of these additives Hydrated lime.

Lime works by replacing negative ions on an aggregate surface with positive calcium ions, resulting in better asphalt binder- aggregate adhesion. The other way to reducing water damage by using polymer as asphalt modifying materials. The polymer tends to change the physical nature of bitumen, and they are able to modify such physical properties as the softening point and brittleness of the bitumen. Elastic recovery/ ductility can be also improved.This in turn will alter the properties of the aggregate/ bitumen mixtures in which the modified bitumen is used. One type of these polymers, Styrene-Butadiene- Styrene (SBS). SBS is a copolymer that used is for modifying asphalt mixtures and developed it resistance for moisture damage, and low temperature cracking.

With this introduction and simple information, the main objective for this study is to investigate on the effect of adding SBS polymer on the moisture damage for asphalt mixtures. The SBS will be used with content (0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4%) by the asphalt weight, and performance tests including on (Marshall Test), (Indirect Tensile test), and (Index of Retained Strength test).

2-Literature review

Polymers, which are the most commonly used recently as binder modification, classified into four main categories, namely: Plastic, Elastomers, Fibers, and Coatings **(Isacsson *et al.*, 1995).** Among polymers, the elastomer styrene-butadiene- styrene (SBS) block copolymer is the most widely used one. It has been identified that SBS can improve the mechanical properties of mixtures such as ageing **(Cortize *et al.*, 2004)**, permanent deformation**(Tayfur, *et al.*,2007; Vlachovicova *et al.*,2007)** , low temperature cracking **(Isacsson *et al.*,1997)**,and moisture damage resistance **(Shulers *et al.*, 1990; Won MC *et al.*,1994)**. Following some of international and locally studies on the effect of SBS on the asphalt mixtures performance.

Won Mc and Homk, 1994: Studied the effect of anti striping additives on PMB. They found , the using of polymer such as SBS improves mixture properties to fatigue cracks, rutting resistance, moisture damage, compared with mixtures contain EVA polymer.

Lu X, Isacsson , 1997: Tested the rheological characterization of SBS copolymer modified bitumen. They stated that a significant improvement in the properties of base bitumen was observed when the SBS content increased from 2% to 6% by the weight of asphalt content.

Stuart *et al.*, 2001: Studied the effect of polymer addition on the adhesion force between the aggregate and asphalt binder. They found that mixtures modified by polymer (SBS & SBR), exhibited greater resistance to moisture damage than the unmodified mixtures, due to increased adhesion force to the aggregate, and creating a network with the bitumen.

Awanti, 2008: Evaluated asphalt mixtures modified by SBS polymer. He found that moisture susceptibility of modified mixture is low when it is compared with control mixture, in addition the improvement in Marshall properties, and temperature susceptibility.

Gorkem and Sengoz, 2009: Aimed to determine the effect of additives such as hydrated lime,as well as elastometric(SBS) and plastomeric(EVA) polymer modified bitumen(PMB) on the stripping potential and moisture susceptibility characteristics of hot mix asphalt containing different type of aggregate. The results indicated that hydrated lime addition and polymer modification increased the resistance of asphalt mixtures to the detrimental effect of water. Moreover, it was found that samples prepared with SBS exhibited more resistance to water damage compared to samples prepared with hydrated lime & plastomeric polymer.

Baha and Mehmet, 2009: Studied the effect of using SBS with hydrated lime on the moisture damage sensitivity resistance of asphalt mixtures. They founded that SBS have good effect on moisture damage resistance and increase its resistance.

Al-Hadidy *et al.,* 2010: Studied the properties of modified asphalt binder and stone mastic asphalt concrete (SMAC) containing such as asphalt binder and made a comparison with asphalt cement. They used a mechanistic design approach for estimating the improvement in service life of the pavement or reduction in thickness of SMAC and base layer for the same service life due to modification the SMAC. They showed that the performance of SBS- modified SMAC is slightly better when compared to starch–modified SMAC. Also the pavement consisting of SBS and starch modified SMAC as a surface layer beneficial in reducing the construction materials.

Albayati *et al.*, 2011: Studied the effect of using SBR on the mechanical properties of asphalt mixtures. From experimental results, they concluded that the mixes modified with SBR polymer have shown an improved fatigue and permanent deformation characteristics as well as superior elastic properties as a characterized via resilient modulus.

3-Materail Properties

3-1Asphalt Cement

One kind of asphalt cement is used, with (40-50) penetration grade brought from AL -Daurah refinery. The physical properties of asphalt cement were evaluated according to ASTM standard (ASTM, 2003), and compared with Iraqi specification know as State Corporation for Roads and Bridge (SCRB/R9, 2003), as shown in Table 1.

3-2 Aggregate

The aggregate used in this study (coarse and fine) was originally obtained from AL Najaf quarries. The aggregate was sieved and recombined to meet the requirements of wearing course gradation according to SCRB specification **(SCRB, 2003)**. The physical properties of aggregate are shown in Table2, while Table 3 shows the aggregate gradation.

3-3 Filler

Filler materials represent mineral particles that pass sieve (No.200). Filler used in this study was ordinary Portland cement (Tasluja), at 7% content, which represents average value of SCRB specifications (SCRB, 2003), Table 4 shows the properties of cement filler material.

3-4 Styrene-Butadiene-Styrene (SBS) polymer

The SBS polymer, used in this study, is brought from the State Company for Mining Industry in Baghdad. The SBS added to asphalt binder with a percentage (0.5, 1, 1.5, 2, 2.5, 3, 3.5, and 4%) by the weight of asphalt, Table 5 shows the SBS properties.

4-Experimental Work

4-1 Asphalt concrete mixture design

The asphalt concrete mixture design started by mixing mixture components (aggregate, filler material, and asphalt cement), and determining the optimum asphalt content using the Marshall mix design method in accordance with ASTM D 1559(ASTM,2003). The optimum content was found to be 4.9% by the total weight of sample. This value of the AC content will be constant, to eliminate the effect of asphalt content on the results analysis, Table 6 shows the asphalt concrete mixtures properties for both of unmodified and modified mixtures with different SBS content.

4-2 Indirect Tensile Strength Ratio Test

The indirect tensile ratio test (TSR) was conducted in accordance with AASHTO T283 (AASHTO, 2003), as standard test method to measure the resistance of compacted bitumen mixtures to moisture damage. A static load is increasingly applied at rate of 2.0in/min to the sample until failure. The result of this test is indirect tensile strength (ITS), and tensile strength ratio (TSR). In this test, two groups of samples were used, the first one represent control samples (UN conditional samples) which they tested at 25^{o}c.The second one (conditional samples), were they submerged in water at 60^{o}c for 24 hr, and then tested at 25^{o}c.All samples were compacted to attain 7% air voids. The indirect tensile strength is calculating according equation 1, and the tensile strength ratio calculating according equation 2 as shown below, the minimum TSR value70%.

$$ITS=2P/\pi dt \text{ ——— } (1) \qquad TSR= ITS_{con}/ ITS_{uncon} \text{ ——— } (2)$$

ITS: indirect tensile strength, P: applied load, t: thickness of samples, d: diameter of sample.

TSR: tensile strength ratio, ITS_{con}: indirect tensile strength for conditioned sample, ITS_{uncon}: indirect tensile strength for unconditioned sample.

4-3Index of Retained Strength Test

Index of retained strength test is used to evaluate moisture damage of asphalt concrete mixtures in accordance with ASTM D 1075(ASTM, 2003). It is one of tests required by SCRB specification to be performed an asphalt mixes used in surface course in addition to Marshall tests (AL-Jumaily, 2007). This test intends to measure the loss of cohesion resulting from the action of water on compacted asphalt mixtures. The dimensions of cylinder sample 4 in (101.6mm) in diameter, and 4in (101.6mm) in height. The index of retained strength (IRS) determined according to the below formula. The minimum IRS value is equal to 70%.

$$IRS=S_2/S_1 \text{ ——— } (3)$$

IRS: index of retained strength, S_2: compressive strength of immersion sample, S_1: compressive strength of dry sample.

$$S=2P/\pi dt \text{ ——— } (4)$$

5- Results Analysis and Discussion

5-1 The effect of SBS on Marshall Properties

Based on the data listed in Table 6, the following points showing the effect of SBS content on the Marshall properties:

1. Marshall Stability values of modified mixtures increase as SBS content increase, asphalt mixture contain (4%SBS) has higher stability value by 76%, than control mixture.
2. Flow values increased as the SBS content increased. Asphalt mix contain (4%SBS) has higher flow value by 12%, than control mixture.
3. Air void values decreased as SBS content increased from (0.5%) to (3%), and then increased, this can be explained duo to increasing in the stiffness of asphalt mixture, which effects on compaction efforts.
4. Finally the increase in the SBS content effects on the density value, where the density increases as well as the SBS content increases.

5-2 Effect of SBS on Tensile Strength

Table 7 shows the result of indirect tensile strength test. In order to evaluate the effect of SBS on the moisture damage resistance Figure 1 shows the relation between the TSR and SBS content. The results show that, the ITS for asphalt mixtures modified by SBS at different content are greater than ITS for control mixture in both cases (unconditioned and conditioned). This means, that mixtures containing SBS have higher values of tensile strength at failure under static loading, which indicates grater cohesive strength of SBS modified mixtures, and improves the adhesion and cohesion of binder and don't allow the striping of asphalt from aggregate surface(Baha, 2009**)**. AS shown in figure, the TSR values increase with increase SBS content, expect for mixtures contain SBS at range (0.5-1%), where TSR slightly decrease, on the other hand, no significant change in the TSR value for mixtures contain SBS in a range (3.5-4%). The increasing in TSR values refer, 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, due to chemical reaction between SBS and asphalt binder.

5-3 The Effect of SBS on index of retained Strength

The results of the retained strength test are listed in Table8, and shown in Figure2. The results show that control mixture has IRS equal to 65.2%, which is below the minimum specified limit (70%). The IRS for modified mixtures increases with increasing SBS content as shown in the Figure2. It can be seen, that asphalt mixtures contain SBS as polymer modifier have high resistance to moisture damage, because they have high percentage of index of retained strength in comparison to the control mixture, which means these mixtures have high durability against environmental effects and resist the applied loads.

5-Conclusions

The main objective of this study is to evaluate the effect of SBS on the moisture damage resistance for asphalt mixtures. The following points can be concluded:

1. The asphalt mixtures prepared with using SBS as polymer modified with a range (0.5-4%) have good properties such as Marshall Stability, and air voids, compared with control mixture.
2. The SBS polymer at different content improves the tensile strength, and increase tensile strength ratio, which effect on moisture damage resistance, and adhesion force between aggregate & bitumen. The maximum rate of increasing on TSR values (16%), when SBS equal to 4%.
3. Increasing compressive strength for asphalt mixtures modified by SBS at different content either for unconditioned or conditioned mixtures. The IRS for control mixture is 65.2%, and it's increased to 82%, when SBS content equal to 4%.
4. Based on these tests and their results, it can be concluded that SBS improves Marshall Properties, tensile strength, and compressive strength. The optimum value of SBS with acceptable results (3%), even that (3.5, 4%) have good results, but the effect of SBS on asphalt mixture at this range is slightly change on the asphalt mixture properties, and performance.

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Table1: Physical properties of asphalt cement

Property	ASTM designation	Test result	SCRB specification
Penetration ,25^{o}c, 100gm, 5sec,0.1mm.	D-5	48	40-50
Ductility , 25^{o}c, 5cm/min.	D-113	110	>100
Flash point	D-92	292	Min 232^{o}c
Specific gravity	D-70	1.034	1.05-1.01

Table 2: Physical properties of the aggregate

Property	ASTM Designation	Coarse aggregate	Fine aggregate
Apparent specific gravity	C-127 C-128	2.66	2.67
%water absorption	C-127 C-128	1.42	2.8
%wear (Los angles	C-131	25 %(max30%)	————

Table3: Aggregate gradation (surface course, Type A)

Sevie size(mm)	19	12.5	9.5	4.75	2.36	0.3	0.075
%passing (SCRB)	100	90-100	76-90	44-74	28-58	5-21	4-10
% passing select	100	95	80	60	45	15	7

Table4: Physical properties of mineral filler(ordinary cement)

Property	Test method	Result
%passing sieve No.200	———	96
Specific gravity	ASTM C 128	3.13
Fineness	———	3123

Table5: Physical and mechanical properties of SBS

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

Source: The State Company for Mining Industry
(Time for blending=60 min, Temperature=180^{o}c)

Table6: Properties of asphalt mixtures

Mixture type	Marshall stability,KN	Marshall flow,mm	Air voids,%	Density, gm/cm^3	Stiffness kN/mm	Optimum asphalt content,%
0%SBS	10.00	3.2	4.30	2.312	3.13	4.9
0.5%SBS	12.3	3.39	4.30	2.312	3.63	4.9
1.0%SBS	13.45	3.43	4.27	2.313	3.92	4.9
1.5%SBS	14.4	3.45	4.20	2.321	4.17	4.9
2.0%SBS	14.92	3.56	3.85	2.325	4.19	4.9
2.5%SBS	15.72	3.72	3.62	2.327	4.22	4.9
3.0%SBS	16.37	3.74	3.60	2.331	4.37	4.9
3.5%SBS	16.9	3.60	3.75	2.330	4.69	4.9
4.0%SBS	17.55	3.58	3.8	2.329	4.90	4.9
SCRB	Min 8 Kn	2-4mm	3-5%	-------	-------	4-6%

Table7: Indirect tensile strength and tensile strength ratio results

%SBS	ITS_{uncon} Mpa	ITS_{con} Mpa	%TSR
0	1.173	0.859	73.23
0.5	1.267	0.923	72.86
1.0	1.346	0.979	72.72
1.5	1.278	1.036	75.18
2.0	1.430	1.093	76.43
2.5	1.513	1.198	79.20
3.0	1.681	1.416	84.21
3.5	1.694	1.428	84.34
4	1.710	1.448	84.70

Table8: The effect of SBS content on IRS values

%SBS	S_1	S_2	IRS
0	1.831	1.194	65.2
0.5	1.854	1.294	69.81
1.0	1.891	1.329	70.30
1.5	1.903	1.342	70.50
2.0	2.014	1.515	75.21
2.5	2.145	1.671	77.91
3.0	2.231	1.775	79.58
3.5	2.245	1.822	81.14
4.0	2.251	1.846	82.00

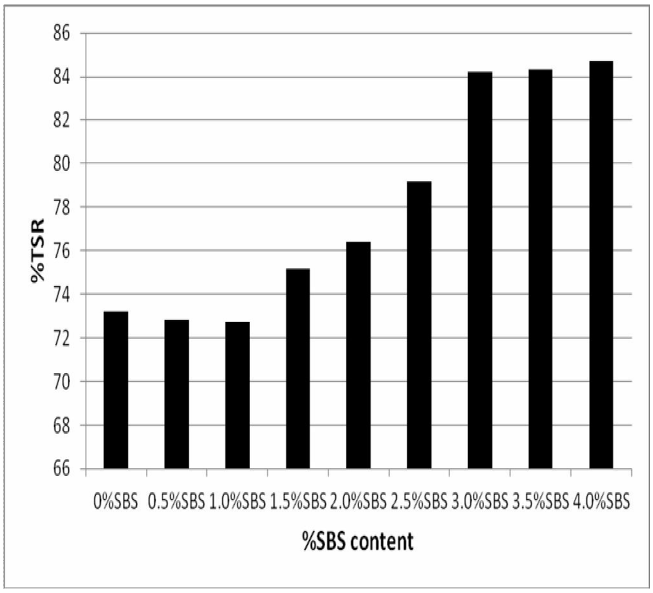

Figure1: The effect of SBS content on the TSR values

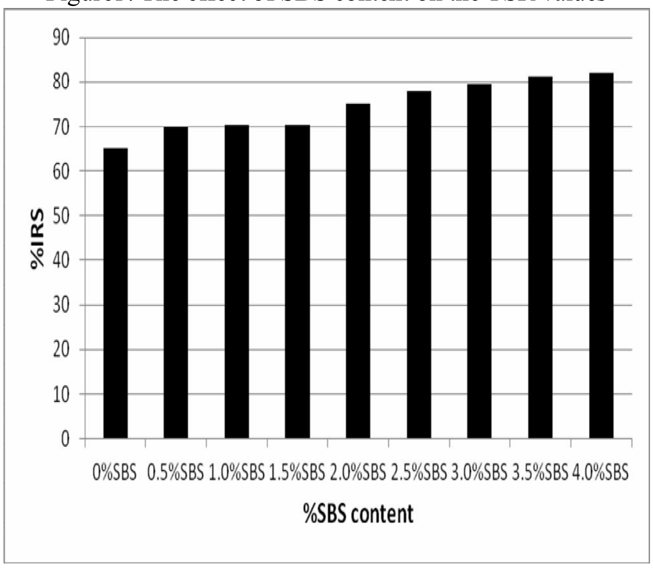

Figure2: The effect of SBS content on the IRS values