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RESEARCH PAPER

Influence of Styrene-Butadiene-Styrene Polymer on Local Asphalt Characteristics

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A B S T R ACT

In this study the effect of Styrene-Butadiene-Styrene (SBS) polymer on local asphalts was investigated by comparing the performance of unmodified asphalt binder and hot mixture with binder and mixtures modified by SBS polymer modified asphalt (SBS-PMA) and its hot mixture. The comparison was made by evaluating the effectiveness of using different percentages (dosages) of this modifier to produce SBS-PMA. The penetration, ductility, elastic recovery, softening point, flash point, penetration and loss on heat tests for the asphalt binder was used. While, Marshall, indirect tensile strength (ITS), and index of retained strength (IRS) tests for the mixture was used in this study as they are the most available and economic. SBS polymer modifier was added to asphalt binders from Kirkuk governorate (KAT) and LANAZ refineries in Erbil governorate-Kurdistan region- Iraq in four percentages 3%, 5%, 7% and 9% by weight of the asphalt binder. The results showed that SBS polymer modifier significantly enhances the performance of asphalt binder and its hot mixture resulting in enhanced flexible pavements. However, adding 5% SBS leads to the best results of the Marshall test properties, and the moisture damage resistance, which increases the pavement performance against the environmental effects. Comparing the experimental results for both unmodified and 5% SBS polymer modified asphalts, showed that the replacement of the unmodified asphalt by 5% SBS polymer modified asphalt increased the stability by 26.00% for KAT asphalt and 21.34 % for LANAZ asphalt. Also, it increased the TSR by 15.63 % for KAT asphalt and 7.95 % for LANAZ asphalt and the IRS by 11.92% for KAT asphalt and 7.11 % for LANAZ asphalt. The regression analysis technique was applied to fit the mathematical relationship between the SBS polymer percentage and the Marshall stability of the hot mixture. Based on this investigation, the polymer modified asphalt is recommended to be used in new constructed roads to help reduce the amount of deterioration and maintenance cost in the region.

Keywords: Styrene-Butadiene-Styrene modified asphalt; SBS modified asphalt; Polymerized asphalt; Polymer modified asphalt; Modified asphalt binder
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1. INTRODUCTION

Asphalt is an old engineering material and has been used as pavement binder and for other purposes. However, the lack of effective unmodified actions during refinery, as well as the need to earning the maximum economic benefits, made researchers and industries pay more attention on asphalt modification. (Zhu, J., et, al, (2014)

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Some of asphalt characteristics enhancers have been adopted to obtain asphalt with enhanced characteristics; additives modification, polymer modification and chemical reaction modification. Polymer modification was found to be among the most commonly used asphalt modifications.

Modifying the asphalt by polymer is the process of adding polymers to asphalt binder. Polymer modifiers which are additive materials are added to the asphalt, to improve its engineering characteristics. As shown in Table (1-1), polymer modifiers for asphalt road construction can be divided into three types, elastomers (75%), plastomers (15%), and natural rubbers (10%). (G. D. Airey, 2003)

Table (1-1): Popular polymers for bituminous modification. (Zhu, J., et, al, (2014)

Categories	Examples	Advantages	Disadvantages
Plastomeres	-Polyethylene (PE) -Polypropylene (PP)	- Good high-temperature properties -Relatively low cost	-Limited improvement in elasticity -Phase separation problems
	-Ethylene-vinyl-acetate (EVA) -Ethylene-butyl-acrylate (EBA)	-Relatively good storage stability -High resistance to rutting	-Limited improvement in elastic recovery -Limited enhancement in low-temperature properties
Thermoplastic elastomers	-Styrene-Butadne-styrene (SBS) - Styrene-isoprene-styrene (SIS)	-Reduced temperature sensitivity -Improved elastic response	-Compatibility problems in some bitumen -Low resistance to heat, oxidation and ultraviolet -Relatively high cost
	-Styrene-ethylene/butylene-styrene (SEBS)	High resistance to heat, oxidation and ultraviolet	-Storage instability problems -Relatively reduce elasticity -High cost

The Styrene Butadiene Styrene (SBS) is the most used and appropriate elastomer polymer for modifying asphalt binder. Using this type of polymer modifier with the asphalt binder increases the elasticity and decreases the viscous component and temperature susceptibility, resulting in enhanced mixture recovering after removing the applied load. As a result, the thermal cracking of the asphalt pavement will be decreased, resulting in reduced permanent deformation. (H. Robinson, 2005)

Plastomers such as Ethylene-Vinyl-Acetate (EVA) and Polyethylene increase the stiffness and viscosity of asphalt while elastomers improve the elastic behavior of asphalt. (H. Robinson, 2005)

As a result, modifying asphalt with SBS leads to increased durability, increased safety, more cost-effective, reduced traffic noise, reduced environmental footprint, improved pavement resistance to rutting and fatigue failure and thickness reduction.

The overall purpose of this study is to evaluate the effect of the addition of Styrene-Butadiene-Styrene (SBS) to the asphalt binder as economic alternative to enhance the characteristics of local used asphalts in Erbil-Kurdistan Region-Iraq. This research study is a laboratory study of the physical properties of SBS-modified asphalt binders and hot mix asphalt using classical tests and the results were then used in mathematical models to predict the influence of the SBS on different asphalt properties.

2. LITRATURE RIVIEW

Recently, many researches were carried out to study the characteristics and performance of SBS polymer modified asphalt. The good properties, solubility in asphalt and suitable cost have made SBS as a popular asphalt binder modifier.

The high aromatics content in asphalt binder can produce a compatible SBS modified asphalt binder. Also, the addition of aromatic oils can improve the compatibility between SBS polymer modifier and asphalt binders with low aromatics content. (J.F. Masson et al, 2003)

In 1980, Piazza et al. (1980) concluded that the features of asphalt binder modified by plastomers and elastomers as demand for thin layer pavements was improved.

In 1997, Isacsson, U. and Zeng HY., tested the rheological characteristics of SBS copolymer modified asphalt. They stated that a significant improvement in the properties of unmodified asphalt was observed when the SBS content increased from 2% to 6% by the weight of asphalt content.

In 2001, Stuart K. D., studied the effect of adding the SBS and SBR polymer modifiers on the adhesion between the components of the hot mixture. He found that adding SBS and SBR polymers to the mixtures, enhance the moisture damage resistance, due to the increased adhesion force.

In 2007, Tayfur et.al. studied the effect of five different polymer modifiers on the rutting performance of asphalt mixtures. SBS mixtures were found as the most resistant with respect to the rutting among the five mixtures.

In 2008, Sengoz, B and Isikya KAT, G. evaluated the properties and microstructure of SBS and ethylene vinyl acetate (EVA) polymer modified asphalt. According to the results, SBS and EVA polymer modifications improved the mechanical properties such as Marshall and ITS, as well as, the unmodified properties of penetration, softening point and temperature susceptibility.

In 2008, Awanti, S. S, Evaluated asphalt mixtures modified by SBS polymer. He found that moisture susceptibility, temperature susceptibility and Marshall properties improved for modified mixtures compared to the unmodified mixtures.

In 2009, Gorkem, C. and Sengoz, B. determined the effect of hydrated lime additive and SBS elastomeric and EVA plastomeric polymer modifiers on asphalt binder. They studied the stripping and moisture susceptibility characteristics of different hot mix asphalts with different types of aggregate. They concluded that adding hydrated lime and SBS and EVA polymer modifiers increased the moisture resistance of asphalt mixtures. Moreover, they found that SBS modified asphalt binders showed more resistance to moisture damage compared to asphalt binder modified with hydrated lime and EVA plastomeric polymer.

In 2009, Baha, Vural Kok, Mehmet Yilamz, investigated the effect of using SBS polymer with hydrated lime on the moisture susceptibility resistance of asphalt mixtures. They determined that SBS polymer modifier improved the moisture damage resistance.

In 2009, Gorkem and Sengoz, B. studied the effect of hydrated lime, SBS and EVA polymer modifiers on stripping and moisture induced damage of hot mixed asphalt. They found that the SBS polymer modified asphalt showed more resistance to water damage.

In 2009, Kok, B. V. and Yilmaz, M. also investigated the effect of adding lime and SBS on the properties of hot mix asphalt. The investigation results indicated that the use of lime as mineral filler and SBS modified asphalt increased the stability, stiffness and strength characteristics of hot mix asphalt.

In 2014, Reem Sabouni and Ahmed Al-Ghazali performed a field examination of asphalt pavements in congested areas in the UAE that recognized main problems: rutting, fatigue cracking, bleeding, raveling, and potholes. Then they evaluated the effectiveness of using Styrene-Butadiene-Styrene (SBS) polymer to modify the asphalt binder to improve the asphalt pavement behavior. Their results showed that, the SBS-PMA had enhanced stability, stiffness, flow and density results. Based on their investigation results, the polymer modified asphalt binder is proposed to be used in new constructed roads to reduce the deterioration and maintenance cost of asphalt pavements in the UAE.

In 2015, Huang, W., studied the effect of cross-linking agent and SBS content on asphalt binder using the multiple stress creep recovery test (MSCR). He concluded that the effect of increasing SBS was more effective at lower SBS content.

In 2018, Dr. Ali Fadhil Naser, studied the effect of styrene butadiene styrene (SBS) polymer modifier on the asphalt binder and its hot mixtures. He studied the asphalt mixture which was used in the rehabilitation of some highways in Baghdad and Al-Basra in Iraq. The results showed that adding SBS Polymer to the asphalt binder improved the mechanical properties of both the asphalt binder and its hot mixture. Therefore, he recommended the use of SBS modified hot mixture asphalt for new pavements and in rehabilitation of the existing flexible pavements.

In 2020, Mirka Pataras, et al, evaluated the addition of Styrene Butadiene Styrene (SBS) and Ethylene Vinyl Acetate (EVA) polymers to improve the characteristics of the asphalt binder and its mixture. He used laboratory experiments, material testing and direct field observation. Based on the results, the SBS modified asphalt mixtures showed better results than the unmodified and EVA modified asphalt mixtures.

3. MATERIALS AND TESTING

3.1. Materials

3.1.1. Asphalt

Two types of locally produced asphalts were used in this study. The first is from KAT refinery (Shuan Road / near the village of Saqzli- Kirkuk Province-Iraq) with penetration grade of 60-70 and the second one is from LANAZ refinery (Algower Road- Erbil Province-Iraqi Kurdistan region) with penetration grade of 40-50. ASTM standards (ASTM, 2003) was used in evaluating the physical properties of the asphalt binder, then they compared with Iraqi specifications of the State Corporation for Roads and Bridges (SCRB/R9, 2003). Table (3-1) shows the characteristics and technical indicators of the two unmodified asphalts.

Table Error! No text of specified style in document..1): Characteristics of the unmodified asphalts

Test Properties	Test Method	KAT*	LANAZ**
Specific Gravity	ASTM D70	1.025	1.060
Penetration at 25 °C (1/10 mm)	ASTM D5	56.0	43.0

Ductility at 25 °C (cm)	ASTM D113	104.6	100.4
Softening Point (°C)	ASTM D36	46.0	52.0
Flash Point (℃)	ASTM D92	240	290
Penetration after RTFO test at 163°C (℃)	ASTM D2872	40.0	20.0
Loss On Heat %	ASTM D2872	0.60	0.63
Elastic Recovery at 25 °C	ASTM D6084	20.0%	9.0 %
*From KAT refinery - Kirkuk-Iraq. **From LANAZ refinery - Erbil- Kurdistan-Iraq			

3.1.2. SBS Modifier

The SBS polymer is brought from the State Company for Mining Industry which is a material company in Baghdad. This type was selected, as it is used in Erbil, Kurdistan-Iraq. Technical indicators of the SBS modifier are listed in Table (3-2), and a sample of SBS which was used in this study is shown in Figure (3-1).

Table (3-2): Technical Indicators of SBS polymer Modification used in this study from product data sheet.

Technical Parameters	Melting point	Density (kg/m^3)	S / B Mass Ratio	Time for blending (min.)	Volatile (%)	Tensile Strength (MPa)	Ash (%)	300% Stress at Definite Elongation (MPa)
Test Results	197	1247	30 / 70	60	=< 0.7	18.5	=<0.2	2.4

Figure (3-1): SBS Used in This Study

Regarding the polymer percentage, Eurobitumen recommends a typical SBS polymer content of around 3.5% by weight in the final product (Eurobitumen life cycle inventory, 2012). While, the manufacturers recommend higher SBS modifier percentages such as 4.5%, 5%, 5.5% and 6% by the weight of asphalt binder. In this study four percentages of 3%, 5%, 7% and 9% were used to obtain the effect of SBS modifier on the unmodified asphalt binder and the asphalt mixture.

3.1.3. Aggregate

The aggregate gradation selected in this study was such as to meet the gradation of both binder and surface courses according to the general specifications for roads and bridges of Iraqi State Organization for Roads and Bridges (SORB-2003). Tables (3-3) and (3-4) show the gradation and the source properties of the selected aggregate respectively. The mineral filler material that passes sieve (No. 200) was ordinary Portland cement from Tasluja factory-Sulaimani-Kurdistan-Iraq. According to SORB specifications 7% by weight was used as shown in Table (3-5).

Table (3-3): Gradation of the Aggregate Used in This Study

U. S. Sieve size		Percentage Passing by Weight of Total Weight		
mm	Imperial	Aggregate used in this study	Binder Course*	Surface Course*
25.0	1 in	-	100	-
19.0	¾ in	100	90-100	100
12.5	½ in	85	70-90	80-100
9.5	3/8 in	75	60-80	70-85
4.75	No. 4	60	42-60	60-80
2.0	No. 10	45	27-47	40-60
1.0	No. 18	35	20-37	28-48
0.60	No. 30	25	15-30	22-40
0.25	No. 60	15	8-20	10-30
0.125	No. 120	10	6-15	8-20
0.075	No. 200	7	5-10	6-12
Asphaltic Cement (% weight of total mix)			4-6	4.5 – 6.5
• SORB specifications				

Table (3-4): Source Properties of the selected aggregate

Property	ASTM Designation	Coarse aggregate	Fine aggregate
Apparent specific gravity	C-127 C-128	2.65	2.66
% water absorption	C-127 C-128	1.44	2.75
% wear (Los Angles)	C-131	25 % (max 30%)	-

Table (3-5): Physical Properties of the Mineral Filler

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

3.2. Testing

3.2.1. Asphalt Binder

A set of asphalt binder tests was conducted to compare the characteristics of the modified asphalt to those of unmodified asphalt using the classical asphalt binder tests as listed in Table (3-6).

Table Error! No text of specified style in document..6 Classical Tests of the asphalt binder

Test Name	Test Method
Penetration at 25 °C	ASTM D5
Ductility at 25 °C	ASTM D113
Elastic Recovery at 25 °C	ASTM D6084
Softening Point °C	ASTM D36
Flash Point	ASTM D92
Loss On Heat %	ASTM D2872
Penetration after RTFO test at 163 °C	ASTM D2872

3.2.2. Asphalt mixture

First SBS was mixed with the asphalt binder for 60 minutes at 180^{o}C, then the mixture components (aggregate, filler material, and SBS modified asphalt binder) was mixed. After that the following tests were conducted on mixtures with unmodified and modified asphalt binders:

1- Marshall test (ASTM D 1559)
2- Indirect Tensile Strength Ratio Test (AASHTO T283)
3- Index of retained strength (ASTM D 1075)

4. RESULTS AND DISCUSSION

4.1. Asphalt Binder

The results of the asphalt binder tests are presented and discussed in the following article.

4.1.1 Penetration

The penetration of unmodified asphalt and SBS-modified asphalt are shown in Table (4-1) for KAT and LANAZ asphalts. The SBS modifier decreased the penetration of both asphalts, due to the hardening of asphalt binder. The effect of SBS on the decrease of penetration of KAT asphalt was higher than that of LANAZ asphalt. The decrease in penetration of KAT modified asphalt with SBS percentages of 3%, 5%, 7%, and 9% was 39.2%, 41.8%, 49.5% and 50.1% respectively, while for LANAZ modified asphalt was 31.4%, 34.4%, 37.6% and 40.9% respectively.

Table (4-1): Effect of SBS Content on Penetration

SBS (%)	KAT		LANAZ	
	Penetration (0.1 mm)	*Decrease (%)	Penetration (0.1 mm)	*Decrease (%)
0	56.0		43.0	
3	34.0	39.2	29.5	31.4
5	32.6	41.8	28.2	34.4
7	28.3	49.5	26.8	37.6
9	28.0	50.1	25.4	40.9

*Decrease with respect to unmodified asphalt

The variance analysis was conducted to know the significance of adding SBS modifier percentage on the penetration of asphalt binder, for both KAT and LANAZ asphalts, as shown in Table (4-2). According to the results, the SBS modifier percentage has considerable influence on the penetration value of KAT asphalt, while it has no considerable influence on the penetration value of LANAZ asphalt. This may be due to the absorption of aromatic hydrocarbon and resin in unmodified asphalt binder by SBS modifier, leading to the swelling behavior and variability in the test results of penetration.

Table (4-2): Variance analysis of penetration for SBS modified asphalt

Source	d f	P – Value
KAT	4	0.0391
LANAZ	4	0.1974

4.1.2 Ductility and Elastic Recovery

The test results of ductility and elastic recovery for both unmodified and SBS modified asphalt binders are given in Tables (4-3) and (4-4). From the results it was concluded that both the ductility and elastic recovery of KAT asphalt was higher than that of LANAZ asphalt.

Table (4-3): Effect of SBS Content on Ductility

SBS (%)	KAT		LANAZ	
	Ductility (cm)	*Decrease (%)	Ductility (cm)	*Decrease (%)
0	104.6		100.4	
3	90	13.96	86.1	14.24
5	84	19.69	80.6	19.72
7	79	24.47	75.8	24.50
9	75	28.30	72.1	28.19

*Decrease with respect to unmodified asphalt

Table (4-4): Effect of SBS Content on Elastic Recovery

SBS (%)	KAT		LANAZ	
	Elastic Recovery (%)	*Increase (%)	Elastic Recovery (%)	*Increase (%)
0	25		27.1	
3	65	160	60.6	123.6
5	75	200	64.8	139.1
7	85	240	68.3	152.0
9	95	280	65.0	139.9

*Increase with respect to unmodified asphalt

The ductility decreases, while the elastic recovery increases with the increase of SBS modifier percentage. This means that the SBS modifier improves both the low and high temperature performances of the asphalt binder. This is because the higher the ductility, the higher the low-temperature crack resistance of asphalt binder. Also, the higher the elastic recovery of asphalt binder, the better high temperature, low temperature, fatigue and durability performances.

The variance analysis for the effect of SBS polymer modifier on the ductility and elastic recovery of asphalt binder was conducted and listed in Table (4-5). The results of ductility and elastic recovery for SBS polymer modified asphalt shows that SBS modifier has a significant effect on the ductility and elastic recovery of asphalt binder. The P-value for KAT asphalt was lower than that of LANAZ asphalt, which means that the effect of SBS modifier on the ductility and elastic recovery for KAT asphalt was greater than that of LANAZ asphalt.

Table (4-5): Variance analysis result of ductility and elastic recovery for SBS modified asphalt

	Source	d f	P - Value
Ductility	KAT	4	0.0396
	LANAZ	4	0.0465
Elastic recovery	KAT	4	0.0016
	LANAZ	4	0.0095

4.1.3 Softening point

The results of softening point of the asphalt binder with the different SBS polymer modifier percentages are shown in Table (4-6). The addition of SBS polymer modifier increases the softening point temperature for the asphalt binders from both sources comparing to the unmodified asphalt binders. This increase is due to the stiffening of SBS polymer modified asphalt binder resulting in more resistance to high temperature deformations especially the permanent deformation or rutting.

Table (4-6): Effect of SBS Content on Softening Point

SBS (%)	KAT		LANAZ	
	Softening point (°C)	*Increase (%)	Softening point (°C)	*Increase %
0	46.3		52.0	
3	50.0	7.99	59.0	13.7
5	74.7	61.33	67.5	29.8
7	92.0	98.70	84.5	62.5
9	95.2	105.62	96.1	84.4

*Increase with respect to unmodified asphalt

The softening point of SBS polymer modified asphalt with the percentages of 3%, 5%, 7% and 9% increased by 7.99 %, 61.33%, 98.70% and 105.62% respectively for KAT asphalt. While, the increase was 13.7%, 29.8%, 62.5% and 84.4% respectively for LANAZ asphalt.

The variance analysis for the softening point of the asphalt binder with different SBS polymer modifier percentages was conducted and listed in Table (4-7). It is clear from the Table that the SBS polymer modifier has significant effect on improving the softening point of both KAT and LANAZ asphalt binders. This means that the addition of SBS polymer modifier improves the high temperature performance of asphalt binder. The P-value of the two types of asphalt binder in the variance analysis was compared and the results showed that the P-value for KAT asphalt was lower than that of LANAZ asphalt. Therefore, the improving effects of SBS polymer modifier on the softening point for KAT asphalt were more than that of LANAZ asphalt.

Table (4-7): Variance analysis result of softening point for SBS modified asphalt

Source	d f	P – Value
KAT	4	0.0067
LANAZ	4	0.0074

4.1.4 Flash point

The flash point of KAT asphalt was lower than that of LANAZ asphalt. The flash point of asphalt binder increases with the increase of SBS polymer modifier percentage for both asphalts, which means that the SBS polymer modifier improves the safety of using the asphalt binder. The results are given in Table (4-8).

Table (4-8): Effect of SBS Content on Flash Point

SBS (%)	KAT		LANAZ	
	Flash point (°C)	*Increase (%)	Flash point (°C)	*Increase (%)
0	240		290	
3	270	12.5	315	8.6
5	296	23.3	338	16.6
7	319	32.9	358	23.4
9	338	40.8	365	25.9

*Increase with respect to unmodified asphalt

4.1.5 Loss on Heat

The effect of aging on the loss in weight of asphalt binder after RTFO test due to evaporating of volatile materials was less than 1% as per Iraqi specifications. The loss in weight for KAT asphalt was higher than LANAZ Asphalt because KAT Asphalt's grade is higher which means that it contains more volatile materials. The increase in SBS percentage increases the loss in weight of asphalt as listed in Table (4-9).

Table (4-9): Loss in Weight of Asphalt Binder After RTFO Aging

SBS (%)		0	3	5	7	9
Loss on Weight for KAT Asphalt	Before RTFO (g)	35.00	35.00	35.00	35.00	35.00
	After RTFO (g)	34.91	34.88	34.86	34.85	34.83
	Decrease (%)	0.26	0.34	0.40	0.43	0.49
Loss on Weight for LANAZ Asphalt	Before RTFO (g)	35.00	35.00	35.00	35.00	35.00
	After RTFO (g)	34.95	34.94	34.92	34.90	34.89
	Decrease (%)	0.14	0.17	0.23	0.29	0.31

4.1.6 Penetration After RTFO

The penetration values of the unmodified and modified asphalts before and after aging are tabulated in Table (4-10). Penetration value was decreased due to the stiffening of asphalt binder.

Table (4-10): Effect of SBS Content and RTFO Aging on Penetration

SBS (%)		0	3	5	7	9
Penetration for KAT Asphalt	Before RTFO (0.1mm)	56.0	34.0	32.6	28.3	28.0
	After RTFO (0.1mm)	51.0	32.0	31.2	27.4	27.9
	Decrease for Designated SBS Content (%)	8.9	5.9	4.3	3.2	0.4
	Decrease after RTFO with respect to unmodified asphalt (%)	8.9	42.9	44.3	51.1	50.2
Penetration for LANAZ Asphalt	Before RTFO (0.1mm)	43.0	29.5	28.2	26.8	25.4
	After RTFO (0.1mm)	39.8	28.9	27.0	26.2	24.9
	Decrease for Designated SBS Content (%)	7.4	2.0	4.3	2.2	2.0
	Decrease after RTFO with respect to unmodified asphalt (%)	7.4	32.8	37.2	39.1	42.1

4.1.7 Ductility and Elastic Recovery after RTFO The RTFO aging leads to decrease the ductility and elastic recovery due to the stiffening of asphalt binder as shown in Tables (4-11) and (4-12).

Table (4-11): Effect of SBS Content and RTFO Aging on Ductility

	SBS (%)	0	3	5	7	9
Ductility for KAT Asphalt	Before RTFO (cm)	104.6	90	84	79	75
	After RTFO (cm)	51	45	42	38	37
	Decrease for Designated SBS Content (%)	51.2	50.0	50.0	51.9	50.7
	Decrease before RTFO with respect to unmodified asphalt (%)	0.0	14.0	19.7	24.5	28.3
	Decrease after RTFO with respect to unmodified asphalt (%)	51.2	57.0	59.8	63.7	64.6
Ductility for LANAZ Asphalt	Before RTFO (cm)	100.4	86.1	80.6	75.8	72.1
	After RTFO (cm)	49	42	40	38	36
	Decrease for Designated SBS Content (%)	51.2	51.2	50.4	49.9	50.1
	Decrease before RTFO with respect to unmodified asphalt %	0.0	14.2	19.7	24.5	28.2
	Decrease after RTFO with respect to unmodified asphalt (%)	51.2	58.2	60.2	62.2	64.1

Table (4-12): Effect of SBS Content and RTFO Aging on Elastic Recovery

	SBS (%)	0	3	5	7	9
Elastic Recovery for KAT Asphalt	Before RTFO (cm)	25.5	65.7	75.2	85.4	95.2
	After RTFO (cm)	22.7	58.3	66.5	75.3	83.4
	Decrease for Designated SBS Content (%)	11.0	11.3	11.5	11.8	12.4
	Increase before RTFO with respect to unmodified asphalt (%)	0.0	157.6	194.9	234.9	273.3
	Increase after RTFO with respect to unmodified asphalt (%)	11.0	128.5	160.9	195.3	227.2
Elastic Recovery for LANAZ Asphalt	Before RTFO (cm)	27.1	60.6	64.8	68.3	65
	After RTFO (cm)	24.66	55.15	58.97	62.15	59.15
	Decrease for Designated SBS Content (%)	9.0	9.0	9.0	9.0	9.0
	Increase before RTFO with respect to unmodified asphalt (%)	0.0	123.6	139.1	152.0	139.9
	Increase after RTFO with respect to unmodified asphalt (%)	9.0	103.5	117.6	129.3	118.3

4.1.8 Softening Point after RTFO

The softening point temperature increased after short term (RTFO) aging. At high SBS modifier contents, a continuous polymer phase occurs, which explains the lower differences in the increase of softening point values. The results before and after aging are given in the Table (4-13).

Table (4-13): Effect of SBS Content and RTFO Aging on Softening Point

	SBS (%)	0	3	5	7	9
Softening Point for KAT Asphalt	Before RTFO (°C)	46.3	50	74.7	92	95.2
	After RTFO (°C)	61.3	57	76.1	87.8	91.2
	Increase for Designated SBS Content (%)	32.4	14.0	1.9	-4.6	-4.2
	Increase before RTFO with respect to unmodified asphalt (%)	0.0	8.0	61.3	98.7	105.6
	Increase after RTFO with respect to unmodified asphalt (%)	32.4	23.1	64.4	89.6	97.0
Softening Point for LANAZ Asphalt	Softening Point Before RTFO (°C)	51.93	56.5	83.1	101.9	106
	Softening Point After RTFO (°C)	67.5	63.33	84.96	96.02	102.3
	Increase for Designated SBS Content (%)	30.0	12.1	2.2	-5.8	-3.5
	Increase before RTFO with respect to unmodified asphalt %	0.0	8.8	60.0	96.2	104.1
	Increase after RTFO with respect to unmodified asphalt (%)	30.0	22.0	63.6	84.9	97.0

4.2. Asphalt Mix

In order to compare the characteristics of the SBS modified asphalt binder to the unmodified asphalt, Marshall, indirect tensile strength ratio and the Index of retained strength tests were conducted on the modified and unmodified asphalt mixtures for both asphalts.

4.2.1. Marshall Test

The optimum asphalt binder content was determined by conducting Marshall test on the prepared specimens for both sets of unmodified and SBS polymer modified asphalt mixes. The results show that the optimum asphalt content is between 4.5% and 4.0% by the total weight of sample for KAT asphalt and between 4.7% and 4.4% for LANAZ asphalt as listed in Table (4-14).

Table (4-14): Effect of SBS on OAC

SBS (%)	Optimum Asphalt Content (%)	
	KAT	LANAZ
0	4.5	4.7
3	4.3	4.6
5	4.2	4.5
7	4.1	4.4
9	4.0	4.4

The statistical analysis showed that SBS modifier content have significant influence on the optimum asphalt content for both KAT and LANAZ asphalts as listed in Table (4-15).

Table (4-15): Variance analysis of OAC for SBS modified asphalt		
Source	d f	P – Value
KAT	4	0.00005
LANAZ	4	0.00001

Therefore, the optimum asphalt content for the unmodified asphalt which is equal to 4.5% for KAT asphalt and 4.7% for LANAZ asphalt was used in this study for all mixes to eliminate the effect of asphalt content on the results.

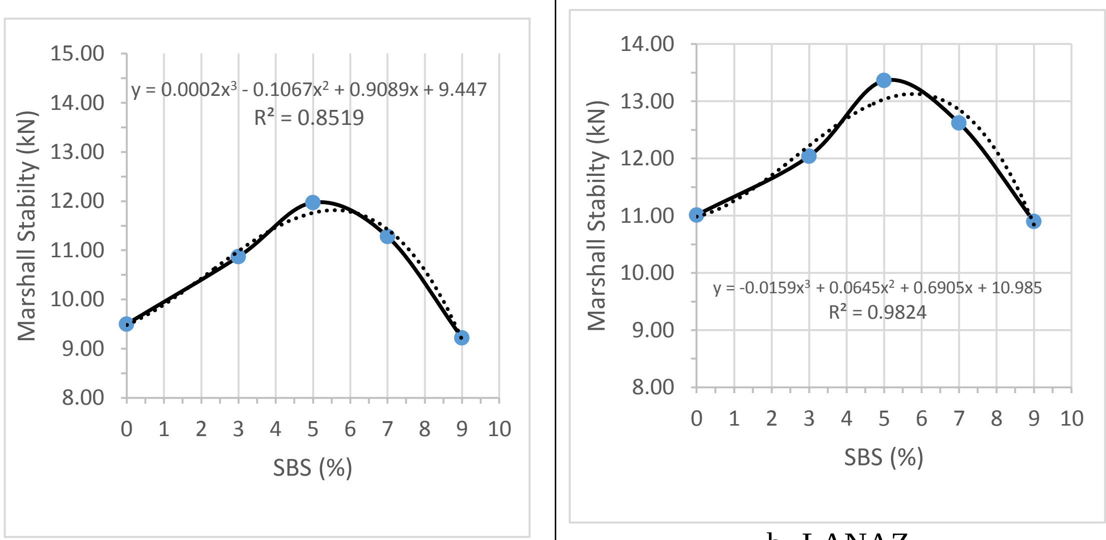
The stability, flow, density and air voids of the unmodified and SBS modified asphalt mixes were studied by conducting Marshall test on the prepared specimens for both sets using the optimum asphalt content for the unmodified mix (e.g., 4.5% for KAT and 4.7% for LANAZ). The results are listed in Tables (4-16) and (4-17) and shown in Figure (4-1).

Table (4-16): Effect of SBS Content on Marshall Test Results for KAT Asphalt

SBS %	Stability kN	Increase in Stability (%)	Flow mm	Bulk Density (g/cm^3)	Gm (g/cm^3)	VTM %	VMA %	OAC %	VFA %
0	9.50	0.00	3.19	2.281	2.416	5.588	15.942	4.5	64.95
3	10.87	12.60	3.44	2.338	2.416	3.228	13.583	4.5	76.23
5	11.97	20.63	3.79	2.34	2.416	3.146	13.500	4.5	76.70
7	11.28	15.78	4.26	2.347	2.416	2.856	13.210	4.5	78.38
9	9.22	-3.04	4.67	2.349	2.416	2.773	13.127	4.5	78.87

Table (4-17): Effect of SBS Content on Marshall Test Results for LANAZ Asphalt

SBS %	Stability kN	Increase in Stability (%)	Flow mm	Bulk Density (g/cm^3)	Gm (g/cm^3)	VTM %	VMA %	OAC %	VFA %
0	11.01	0.00	3.05	2.327	2.442	4.709	15.640	4.7	69.89
3	12.04	8.55	3.52	2.337	2.442	4.300	15.231	4.7	71.77
5	13.36	17.59	3.83	2.342	2.442	4.095	15.026	4.7	72.75
7	12.62	12.76	4.23	2.345	2.442	3.972	14.903	4.7	73.35
9	10.90	-1.01	4.53	2.378	2.442	2.621	13.552	4.7	80.66



b- LANAZ

a- KAT

Figure (4-1): Effect of SBS Content on Marshall Stability

The effect of SBS content on the properties of asphalt mix determined by Marshall test are as follows:

1. Marshall Stability values of modified mixtures increase as SBS content increases to certain content and then decreases. The higher increase in stability value for KAT asphalt was 20.63% at 5% SBS content comparing to the unmodified mix. While for LANAZ asphalt it was 17.59% at 5% SBS. This increase in stability can be due to improved adhesion between the aggregate and bitumen.
2. Flow values also increased as the SBS content increased. The maximum values were 4.67 mm and 4.53 mm for KAT and LANAZ asphalts respectively. While for the unmodified mix they were 3.19 mm and 3.05 mm for KAT and LANAZ asphalts respectively.
3. The increase in the SBS content also increases the density of the asphalt mix. The maximum densities were 2.349 g/cm^3 and 2.378 g/cm^3 for KAT and LANAZ asphalts respectively. While for the unmodified mixes they were 2.281 g/cm^3 and 2.327 g/cm^3 for KAT and LANAZ asphalts respectively.
4. Values of air void, voids in total mix (VTM), and voids in mineral aggregate (VMA) decreased as SBS content increased. The minimum values of voids in total mix (VTM) were 2.773% and 2.621% for KAT and LANAZ asphalts respectively. While for the unmodified mixes they were 5.588% and 4.709% for KAT and LANAZ asphalts respectively.

4.2.2. Indirect Tensile Strength (ITS)

The results show that the SBS improves the ITS of the mix at failure under static loading, due to the improve in adhesion and cohesion of asphalt binder. This improve in the adhesion and cohesion of asphalt binder results in better moisture resistance which reduces the striping of asphalt from aggregate surface. The tensile strength ratio (TSR) was determined for different SBS polymer modifier contents for conditioned and unconditioned samples. This was done to evaluate the effect of SBS polymer modifier on the moisture damage resistance, the results are listed in Table (4-18).

Table (4-18): Effect of SBS Content on Indirect Tensile Strength (ITS) and Tensile Strength Ratio (TSR)

SBS (%)	KAT			LANAZ		
	ITS (MPa)		TSR (%)	ITS (MPa)		TSR (%)
	Unconditioned	Conditioned		Unconditioned	Conditioned	
0	1.173	0.859	73.23	1.295	1.039	80.23
3	1.681	1.416	84.24	1.416	1.219	86.09
5	1.710	1.448	84.68	1.527	1.331	87.16
7	1.352	1.157	85.58	1.467	1.284	87.53
9	1.138	0.980	86.12	1.290	1.114	86.36

The increase in SBS polymer content up to 5%, results in maximum increase of the indirect tensile strength and then decreases for both asphalts. These values for asphalt binder from KAT refinery was 1.710 MPa for unconditioned asphalt samples and 1.448 MPa for conditioned asphalt samples with TSR equal to 84.68%. While, for asphalt binder from LANAZ refinery it was 1.527 MPa for unconditioned asphalt samples and 1.331 MPa for conditioned asphalt samples with TSR equal to 87.16%.

4.2.3. Index of Retained Strength

The index of retained strength (IRS) increases with increasing SBS polymer content as listed in Table (4-19). The unmodified mixture of KAT asphalt has IRS equal to 78.62%, which is below the minimum specified limit of 80%. This means that this asphalt should be modified. Asphalt mixtures containing SBS polymer modifier have high percentage of index of retained strength in comparison to the unmodified mixture. This results in higher resistance to moisture damage, durability against environmental effects and resistance to the applied axle loads.

Table (4-19): Effect of SBS Content on Index of Retained Strength (IRS)						
SBS (%)	KAT			LANAZ		
	Compressive Strength (MPa)		IRS (%)	Compressive Strength (MPa)		IRS (%)
	Unconditioned	Conditioned		Unconditioned	Conditioned	
0	2.848	2.239	78.62	3.161	2.703	85.50
3	3.180	2.778	87.36	3.432	2.990	87.13
5	3.418	3.007	87.99	3.680	3.370	91.58
7	3.275	2.784	85.00	3.565	3.164	88.76
9	2.763	2.312	83.69	3.130	2.771	88.54

The asphalt binder from both sources, with the increase in SBS polymer content up to 5%, show a maximum increase of the index of retained strength and then decreases. This value for asphalt binder from KAT refinery was 3.418 MPa for unconditioned asphalt samples and 3.007 MPa for conditioned asphalt samples with IRS equal to 87.99%. While, for asphalt binder from LANAZ refinery it was 3.680 MPa for unconditioned asphalt samples and 3.370 MPa for conditioned asphalt samples with IRS equal to 91.58%.

4.3. Selecting Suitable SBS Content

The higher increase in stability value was at 5% SBS content comparing to the unmodified mix. This increase for KAT asphalt was 26.00 %, while for LANAZ asphalt it was 21.34%. Therefore, the 5% SBS content may be considered as the best percentage by weight. The remaining Marshall parameters for 5% SBS are given in Table (4-20). While, Table (4-21) gives the physical properties of asphalt binder at 5% SBS.

Table (4-20): Effect of 5% SBS Content on Marshall Test Results								
		Stability kN	Flow mm	Density g/cm^3	VTM %	VFA %	TSR %	IRS %
Asphalt Source	KAT	11.97	3.79	2.345	3.146	76.70	84.68	87.99
	LANAZ	13.36	3.83	2.342	4.095	72.75	87.16	91.58
Specifications	Binder	Min. 7kN	2 – 4		3-7	60-80		>80%
	Wearing	Min. kN	2 – 4		3-5	70-85		>80%

Table (4-21): Physical Properties of Asphalt Binder at 5% SBS						
Test Properties	KAT			LANAZ		
Characteristic	0% SBS	5% SBS	% Change	0% SBS	5% SBS	% Change
Penetration at 25 °C (1/10 mm)	56.0	32.6	41.8	43.0	28.2	34.4
Ductility at 25 °C (cm)	104.6	84.0	19.7	100.4	80.6	19.7
Elastic Recovery at 25 °C (%)	20.0	75.0	200.0	9.0	64.8	139.1
Softening Point (°C)	46.0	74.7	61.3	52.0	67.5	29.8
Flash Point (℃)	240.0	296.0	23.3	290.0	338.0	16.6
Penetration after RTFO test at 163°C (1/10 mm)	40.0	31.2	4.3	20.0	27.0	4.3
Loss On Heat (%)	0.60	0.40	33.3	0.63	0.23	63.5

5. CONCLUSIONS

The results of this study indicated that the use of SBS modified asphalt in flexible pavements would result in improved strength and more durable pavements with longer life. The best content of SBS which has the higher stability is 5 % by weight of asphalt cement. Therefore, the modification for this percentage is listed below:

1- The SBS modifier lowered the penetration of both asphalts. The decrease in penetration of KAT was 41.8%, while for LANAZ modified asphalt was 34.4%.
2- For both sources, the ductility of asphalt binder decreases significantly, while the elastic recovery of asphalt binder increases significantly with the increase of SBS modifier percentage. This means that the addition of SBS modifier could improve the low temperature performance of the asphalt binder.

   The ductility and elastic recovery of KAT asphalt was higher than that of LANAZ asphalt. The decrease in ductility of KAT modified asphalt was 19.7%, while for LANAZ modified asphalt was 19.7%. The increase in elastic recovery of KAT modified asphalt was 200.0%, while for LANAZ modified asphalt was 139.1%.
3- The addition of SBS modifier increases the softening point temperature of both asphalt binders. This means that the addition of SBS modifier could improve the

temperature performance of asphalt binder at high temperatures. The softening point of SBS modified asphalt increased 61.33% for KAT asphalt, while the increase was 29.8% for LANAZ asphalt.

4- The flash point of asphalt binder increases with the increase of SBS modifier percentage, which means that the addition of SBS modifier could improve the safety of using the asphalt binder. The flash point of SBS modified asphalt increased 23.3% for KAT asphalt. While, the increase was 16.6% for LANAZ asphalt.
5- The effect of aging on the asphalt binder loss in weight after RTFO test was less than 1% as per Iraqi specifications. The loss on heat of SBS modified asphalt decreased 33.3% for KAT asphalt, while the decrease was 63.5% for LANAZ asphalt.
6- The SBS polymer modification improves the mechanical properties of hot mixture asphalt and have significant influence on the optimum asphalt content for both KAT and LANAZ asphalts. The optimum asphalt content is between 4.0% and 4.5% by the total weight of sample for KAT asphalt and between 4.4% and 4.7% for LANAZ asphalt.
7- Marshall Stability values of modified mixtures increase as SBS content increases to 5% content and then decreases. The higher stability value at 5% SBS content for KAT asphalt was 11.97 kN (20.63% increase), while it was 13.36 kN (17.59% increase) for LANAZ asphalt.
8- Flow values for both asphalts were also increased as the SBS content increased. The values for modified asphalt binder were 3.79 mm and 3.83 mm for KAT and LANAZ asphalts respectively. While for the unmodified mix they were 3.19 mm and 3.05 mm for KAT and LANAZ asphalts respectively.
9- The density of the modified asphalts was increased 14.6% and 0.6% for KAT and LANAZ asphalts respectively.
10- Values of air void, voids in total mix (VTM), and voids in mineral aggregate (VMA) decreased as SBS content increased. The decrease in voids in total mix (VTM) was 43.7% and 13.0% for KAT and LANAZ asphalts respectively.
11- The increase in SBS polymer content increases the tensile strength ratio resulting in better moisture resistance. It was 84.68% for asphalt binder from KAT, while it was 87.16% for asphalt binder from LANAZ refinery.
12- The increase in SBS polymer content improves the index of retained strength (IRS) which is an indicator of better moisture resistance. This value for asphalt binder from KAT refinery was 87.99%, while for asphalt binder from LANAZ refinery it was 91.58%.

6. Recommendations and Future Research

6.1 Recommendations

1. The significant range of SBS is between (3-7) % by weight, but as the higher increase in Marshall stability value, indirect tensile strength (ITS), and index of retained strength for KAT and LANAZ asphalts was at 5% SBS polymer content, therefore, it is recommended that 5% of SBS polymer content is the most preferable dosage rate needed to attain a reasonably acceptable characteristics of asphalt mixture. Therefore, the use of 5% SBS polymer modified asphalt binder in newly constructed pavements and for maintenance is recommended, especially in heavy traffic areas to reduce the pavement deterioration in the study area.
2. The optimum asphalt binder content for SBS modified asphalt binder to be 4.2% and 4.5% for KAT and LANAZ asphalts respectively.
3. It is possible to state, based on both binder and mixture test data, that the SBS polymer modified asphalt is able to deliver an appropriate resistance to high and low temperature failures. This finding will assist in the design of better hot asphalt mixtures.

6.2 Future Research

The authors of this study recommend that future research on asphalt polymer modification take into consideration the following points:

1- Effect of long aging on performance of polymer modified asphalt binder.
2- The Recyclability of polymer modified asphalt binder.
3- The effect of storage on the characteristics of polymer modified asphalt binder.

4- The use of asphalt binders from other refineries in Kurdistan region-Iraq with different penetration grades.
5- Evaluating the use of polymer modification using SUPERPAVE tests.

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