Hindawi
Advances in Civil Engineering
Volume 2023, Article ID 7151175, 13 pages
https://doi.org/10.1155/2023/7151175

Research Article

Improvement of Engineering Properties of Asphalt Binder and Mixture by Using SBS Additive Material

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Received 7 December 2022; Revised 28 February 2023; Accepted 7 June 2023; Published 20 June 2023

Academic Editor: Afaq Ahmad

Rutting, thermal cracking, and stripping are among the most severe distress types in asphalt pavement. In this study, a specified type of styrene-butadiene-styrene (SBS) was used as a modifier for a low viscosity asphalt binder G80/100 (PG 58-22) to overcome the issues of the distresses in the asphalt mixture. The mixing process had been evaluated by using fluorescent microscopy. The control- and SBS-modified binders were subjected to all conventional and Superpave binder tests. The Hamburg wheel tracker (HWT) and indirect tensile strength ratio (ITSR) tests were conducted to evaluate the engineering properties of the control and modified asphalt mixtures. The used SBS percentages were 1, 2, 3, 4, and 5% of the total weight of the binder. The results showed lower penetration, higher softening point, viscosity, and elastic recovery. The dynamic shear rheometer (DSR) and bending beam rheometer (BBR) tests showed an increasing SBS% leading to an increase in both values of high and low temperatures of the asphalt performance grade (PG). The tensile strength ratio and Hamburg wheel tracker tests' results showed that the highest TSR and rutting parameter values were obtained at 3% SBS, which was the optimum SBS content for the asphalt mixture and the resulted modified asphalt is PG76-16.

1. Introduction

Nowadays, more frequent and heavier traffic loads placed on the roads have been growing. An increase in the traffic loads shortens the pavements' service life especially when associated with inappropriate weather conditions [1, 2]. In order to prevent the degradation of the asphalt pavement, it is vital for it to have the best serviceability during live performance with an appropriate structural number [3]. To improve the qualities of the asphalt mixture used in road construction, a number of techniques have been developed. One of the techniques involves adding different modifiers to the asphalt binder and mixture.

Today, polymers are the most frequently utilized additives to improve asphalt qualities. The regular asphalts mixed with the polymers are known as polymer-modified asphalt (PMA). The SBS, crumb rubber (CR), styrene-butadiene rubber (SBR), ethylene-vinyl acetate (EVA), and polyethylene are among the polymers that are frequently utilized for modifying asphalt [4, 5]. The modifiers can decrease rutting distresses by increasing the aging resistance of the asphalt concrete to the high temperature. Also, they can prevent the issue of the binder running off with the aggregate by enhancing the adhesive qualities [6].

The asphalt mixtures combined with the SBS modifier produced significantly better performance regarding the fatigue cracking distress than the conventional mixtures [7].

The rutting resistance of asphalt mixtures is improved by using SBS modifier with higher performance properties [8, 9]. Generally, SBS can thoroughly disperse in bitumen as its content being not more than 5% [10].

The wheel tracking test has been used effectively to identify the rutting susceptibility of bituminous mixes. Many specifications are available for wheel tracking rut depths that are specific to the typical mixes, climatic, and traffic loading conditions [11].

There are many types of SBS based on its properties such as the percentages of styrene/butadiene (20/80, 30/70, and 40/60), molecular structure (linear or radial), and the particle size (granular or powder form). Also, the source quality of the SBS is essential [12].

In this research study, the effects of using a radial SBS, 30/70 styrene/butadiene percentages, high-quality manufactured, and powdered form modifier mixed with a soft asphalt binder (G80/100) are investigated. The SBS ratios were 1, 2, 3, 4, and 5%. The asphalt mixture was prepared according to the new approach of the Superpave design method. Also, the regression models were made to obtain the best ratio of SBS that can be utilized for road construction projects. Fluorescent microscope images were taken during the mixing process of asphalt binder with SBS to ascertain the quality of the modified asphalt and dispersion pattern of the additive material.

Unlike most previous studies, the main object of conducting DSR and BBR tests in this study was to obtain the relationship between the PG of the modified asphalt and SBS ratios, which is essential in pavement construction to obtain the required asphalt PG according to the specified climate conditions.

Also, to obtain the optimum SBS ratio, two vital engineering performance tests were conducted on control and modified asphalt mixture, which are as follows: first, the ITSR test that is a part of Superpave specification to evaluate the moisture sensitivity of the mixture and second the HWT test to obtain rutting parameters, stripping inflection point (SIP), and number of passes to failure (N_f) related to SBS ratios. The DSR and BBR tests were conducted to evaluate the control and modified asphalt binder parameters.

2. Materials

2.1. The Asphalt Binder. In this study, a local asphalt binder with penetration grade of (80/100) or (PG 58-22) from Phoenix refinery was used. This low viscosity asphalt is rarely used in the pavement layers construction for hot climate regions; however, after mixing the SBS with the asphalt binder, the chemical alteration was induced, in which a lower grade modifier asphalt was led. Table 1 shows the results of the conventional tests of the control asphalt (0% additives).

2.2. The SBS Additive Material. The SBS used was Pheoprene 1211 porous crumb, high quality powdered form, 30/70 styrene/butadiene percentages, thermoplastic copolymer, and radial structure. The specific gravity of the SBS was 0.79. The particle size distribution of the SBS is shown in Figure 1. The ratios of the SBS that were used with the control asphalt were 1, 2, 3, 4, and 5%.

2.3. Aggregate. The used aggregate was crushed aggregate, which was a product of boulders crushing. Several laboratory tests for the gravel, sand, and filler materials were conducted according to the Superpave specifications as presented in Table 2.

The asphalt concrete course that was considered in this study was the surface course type 3A according to Iraqi specifications because it is the contacted course with high-traffic volume highways and weather.

Table 1: Characteristics of the control (base) asphalt binder.

Test	Test specification	Result
Penetration at 25°C	ASTM D5	90
Softening point (°C)	ASTM D36	46
Ductility at 25°C (cm)	ASTM D113	150
Elastic recovery at 25°C	ASTM D6084	3%
Viscosity centi poise at 135°C	ASTM D4402	252
Flash point (°C)	ASTM D92	277
Specific gravity at 25°C	ASTM D70	1.058
Penetration after RTFOT	ASTM D2872	43
Softening point after RTFOT	ASTM D2872	58
Loss on heat % after RTFOT	ASTM D2872	0.81
Softening point after storage stability	ASTM D6930	Nil

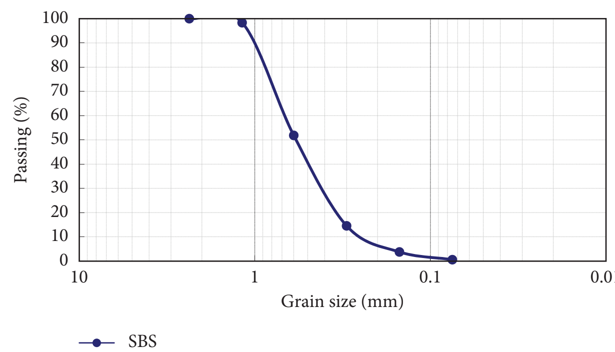

Figure 1: SBS particle size distribution.

3. Methodology

3.1. Modified Asphalt. The mixing process of control asphalt with the SBS was conducted using an oil bath supplied with digital thermometer and internal agitator to spread heat as shown in Figure 2. The asphalt binder was poured in a vertical cylindrical can with a capacity of about 3.5 kg. After adding the specified percentages of the total weight, a vertical stirring mixer was used to mix the SBS with the asphalt binder. Mixing temperature was 180°C, stirring speed of 600 rpm was used to ensure mixing and prevent segregation, and the mixing time was 2 hours. These mixing conditions are similar to the study of researchers in [13, 14] and [15].

During this process, softening point samples were taken to track the change every half hour. After finishing the mixing process, the conventional tests of penetration, softening point, elastic recovery, rotational viscosity (RV), flash point, and specific gravity were conducted. Also, the tests of penetration, softening point, and loss on heat were conducted after the RTFOT and storage stability test. The microscope images were taken for the samples to ensure the SBS dispersion in the asphalt binders. Finally, PG tests that included DSR, RTFOT, PAV, and BBR were conducted to find their PG values, as well as G^*, δ, stiffness, and m-values.

3.2. Aggregate Structure Selection. Three aggregate gradations were designed A, B, and C based on the Superpave control points' limits and specifications, as shown in Figure 3.

Table 2: Aggregate test results.

Type of materials	Test	Symbol	Value	Note	Superpave specifications
Gravel	Apparent specific gravity	GA	2.725	Crushed gravel	
	Bulk specific gravity	GB	2.671		
	Effective specific gravity	GE	2.693		
	Water absorption	W.a %	0.747		
	Abrasions value	A.V %	22.56		
	Gravel angularity	P %	96.6	20% round edge, 80% sharp edge, and all rough surface	95/90%
	Flat and elongated	P %	0.4		max. 10%
Sand	Apparent specific gravity	GA	2.699	Crushed sand	
	Bulk specific gravity	GB	2.535		
	Effective specific gravity	GE	2.617		
	Water absorption	W.a %	2.399		
	Uncompacted air void %	U %	48		min. 45
	Sand equivalent value %	Nil	75		min. 45
Filler	Apparent specific gravity	GA	2.523	Brown filler	
	Bulk specific gravity	GB	2.435		
	Effective specific gravity	GE	2.479		
	Water absorption	W.a %	1.422		

Asphalt concrete tests were performed that included the maximum theoretical specific gravity of the mix (Gmm) for each aggregate gradation. All the above mentioned tests were conducted in the laboratory.

For each of the aggregates A, B, and C, five samples were prepared to be mixed with asphalt by using five percentages (4, 4.5, 5, 5.5, and 6%) of asphalt content. The Gmm for each of the aggregate mixtures were measured in the laboratory. Then, all the mixtures were compacted using the gyratory compacter. The results were used to find voids in mineral aggregate (VMA), void filled with asphalt (VFA), density at initial number of gyrations, design number of gyration, maximum number of gyrations, dust to binder ratio, and specific gravity of compacted mixture at 4% air voids.

Finally, depending on the aggregates' result and Superpave specifications, the passed aggregate B was selected to be used for all the latter mixtures of modified asphalt with SBS. The total number of samples was 15.

3.3. Optimum Asphalt Content for the Modified Asphalt Mixture. Using aggregate B, six asphalt contents were used in the samples of mixtures for all modified asphalt with SBS, including the control sample. The asphalt contents for each sample were 4– 6% or 4.5– 6.5% with an increment of 0.5% depending on the SBS percentage. All samples were compacted using the gyratory compacter, and the optimum asphalt content for each SBS percentages was obtained after the volumetric analysis was performed. The total number of samples was 30.

3.4. ITSR Test (ASTM D4867 and AASHTO T283). The ITS tests were conducted on the control and SBS-modified asphalt mixture samples. Six samples for each percentage of the SBS were prepared to obtain ITSR. Three samples were tested in dry condition, and the other three samples were tested after conditioning through one cycle of freezing and thawing. The samples were prepared using 7% air void as specified and then tested to find the indirect tensile strength of samples; as a result, ITSR was calculated. The total number of samples was 36. Figure 4 shows the samples after testing.

3.5. HWT Tests (AASHTO T324). The HWT test was conducted on the asphalt control mixture and modified asphalt mixture with SBS. The samples had a diameter of 15 cm and height of 6 cm; they were tested using a wheel tracker machine. It was conducted to obtain rutting value versus the number of wheels passing repetitions (1 cycle = 2 passes). The total number of samples was six. Figure 5 shows the wheel tracker with the mounted samples. The passes continued until they reached to 20,000 passes or the rut depth reached to 20 mm as shown in Figure 6. A curve was drawn between the rut depth in mm and number of passes; from this curve stripping inflection point (SIP), the number of passes to failure (N_f) was obtained.

4. Results and Discussion

4.1. Modified Asphalt Binder. Table 3 shows the results of mixing the asphalt binder with SBS. The penetration values decreased, while the softening point increased by increasing the percentages of SBS additive material; it means that the asphalt binder became harder, which is similar to the results of the research studies in [14, 16].

The ductility test was replaced by elastic recovery because the asphalt broke in the early stages in the ductility test due to adding the SBS. The increasing elastic recovery values indicate that the asphalt binder gained more elasticity. The viscosity value increased clearly [17]. The asphalt binder with 5% SBS had a viscosity of nearly 3 Pa.s, which is the maximum limit of viscosity on the Superpave specifications. This was the reason for not increasing SBS% more than 5%.

The flash point values increased slightly. The specific gravity decreased due to adding the light weight of the SBS specific gravity effect. The penetration index increased from negative value to positive value due to the change in

Figure 2: The asphalt and additives mixing process.

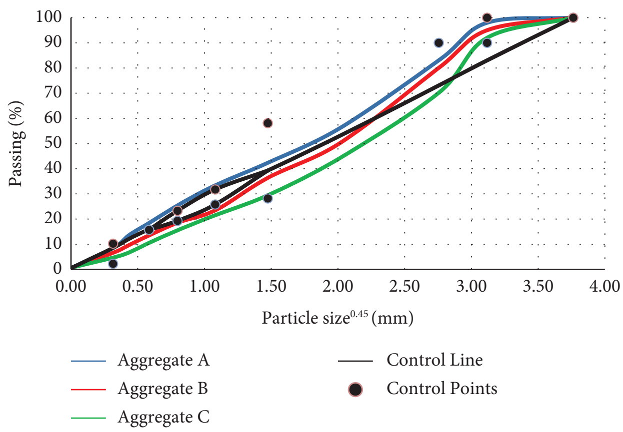

Figure 3: Superpave gradation for 12.5 mm nominal maximum size.

Figure 4: ITSR samples after test.

penetration and softening point, which means that SBS had an effect on the asphalt binder.

Softening point after storage stability test for up and down parts of the mold was increased with the increase of SBS% due to the SBS effect. Penetration and softening point values after the rolling thin film oven test (RTFOT) changed due to hardening of the short-term aging effect of the RTFOT. The percentage of loss value decreased but still was within Superpave limits as the SBS percentage increased; this is reasonable as the modified asphalt became harder [14].

The penetration values after the RTFO test decreased compared with the unaged samples as expected since aging led to evaporation of volatile component in the asphalt binder. The same results were obtained with softening points that increased after the RTFO test.

Table 4 shows the results of the RV test conducted on all modified asphalt samples. The tests were run at 135°C and 170°C. The results of the RV tests were used to find the mixing and compacting temperatures for the modified asphalt mixture samples. This can be achieved using two temperatures, viscosity values, and a viscosity bar chart.

4.2. Statistical Regression Models. Figure 7 shows the SBS percentages versus the conventional tests (penetration, softening point, elastic recovery, and viscosity) with their regression equations and correlation coefficients.

The equation models can be used to find the conventional test values for any required SBS percentages within the percentage range used or to predict any value out of the range. The models are important since SBS additive is costly compared to other asphalt additives.

4.3. Modified Asphalt Microscopic Images. In order to ensure the dispersion of the SBS additive material in the asphalt binder during mixing process, florescent microscope images with magnification power (40x) were taken after adding the SBS additives. Figure 8 shows the SBS particles in asphalt binder represented by yellow spheroid particles. Their number and concentration grew as the SBS percentages increased. The homogenous dispersion and density for adding 3% of SBS were the best result, while for 4% and 5% of SBS, the homogenous dispersion and density started to agglomerate.

4.4. PG Tests. The PG test consisted of two rheometer tests, namely, the DSR and BBR tests. These two tests are essential to determine the high and low temperatures of asphalt binders.

4.4.1. DSR Test. The DSR test gives four important parameters, namely, complex shear modulus (G^*), which is the slope of shear stress to shear strain representing the stiffness of the asphalt, ($G^*/\sin\delta$) which represents rutting parameter, ($G^*.\sin\delta$) represents the fatigue parameter, and phase angle (δ) represents the slope angle of viscous to elastic behavior of the asphalt binder.

The DSR tests were not conducted completely for SBS 5% because the original samples before RTFOT and PAV tests passed 94°C, which is beyond the PG specifications. This was expected due to their high viscosity value, which was near 3 Pa·s.

Table 5 shows all of the results of DSR tests for asphalt binder samples with and without the SBS. The increase in the SBS percentage did not cause increasing or decreasing of DSR parameters G^* or δ due to rising the testing temperature with increasing SBS percentage, but there was an increase in high temperature of PG to satisfy the hot region climate.

Figure 9 shows the value of G^* versus percentage of the SBS content. There is no increasing or decreasing trend in G^* values due to variable test temperature. The values after performing the RTFOT are greater due to aging of the asphalt binder.

Figure 5: Wheel tracker samples.

Figure 6: Wheel tracker sample after test.

Table 3: Test results for asphalt binder mixed with SBS.

SBS (%)	0	1	2	3	4	5	Spec
Asphalt grade	80/100	80/100	80/100	80/100	80/100	80/100	
Penetration 0.1 mm	90	72	52	49	42	40	
Softening point (°C)	46	50	65	76	86	87	
Ductility (cm)	150	Nil	Nil	Nil	Nil	Nil	
Elastic recovery (%)	3	42	82	94	95	96	
Viscosity c.p, 135°C	252	542	889	1171	1910	2819	3000
Flash point (°C)	277	294	295	297	298	299	230
Specific gravity	1.058	1.059	1.060	1.055	1.048	1.035	
Penetration index	−0.80	−0.30	2.08	3.71	4.64	4.64	
Storage stab./soft. pt	Nil	U50D50	U70D60	U80D70	U92D79	U95D80	
RTFOT/penetration	43	35	25	31	29	26	
RTFOT/soft. point	58	66	71	81	87	87	
RTFOT/loss on heat (%)	0.81	0.79	0.77	0.75	0.74	0.74	<1

Table 4: Modified asphalt viscosity results (centi poise).

No.	Asphalt grade	Additives (%)	135°C	170°C	T mix	T compaction
1	80/100	0	252		160	150
2	80/100	SBS 1	542	132	162	152
3	80/100	SBS 2	889	182	170	160
4	80/100	SBS 3	1171	291	180	170
5	80/100	SBS 4	1910	377	186	176
6	80/100	SBS 5	2819	502	190	180

Figure 10 shows the value of delta (δ) versus the SBS percentages. The values of delta after performing the RTFOT were lower than the values of the previous samples for most percentages due to the aging effect.

4.4.2. BBR Test. The BBR test has two outcomes, namely, the stiffness (S) and m-value, which is the slope of stiffness curve at 60 second. Table 6 shows the results of the S and m-values for samples with and without using the SBS. The stiffness values increased and the m-values decreased with increasing SBS percentages at the same temperature. These results indicate that the increase in additive percentages of SBS will lead to higher low temperature.

Table 7 shows the PG results for asphalt mixtures having different SBS percentages. The table shows that increasing SBS percentages led to the increase in high- and low-grade temperatures. For example, the assigned PG for 1% SBS is 64– 22, which changed to 82–10 for 4% of SBS. These results are confirmed by authors in references [17] and [14].

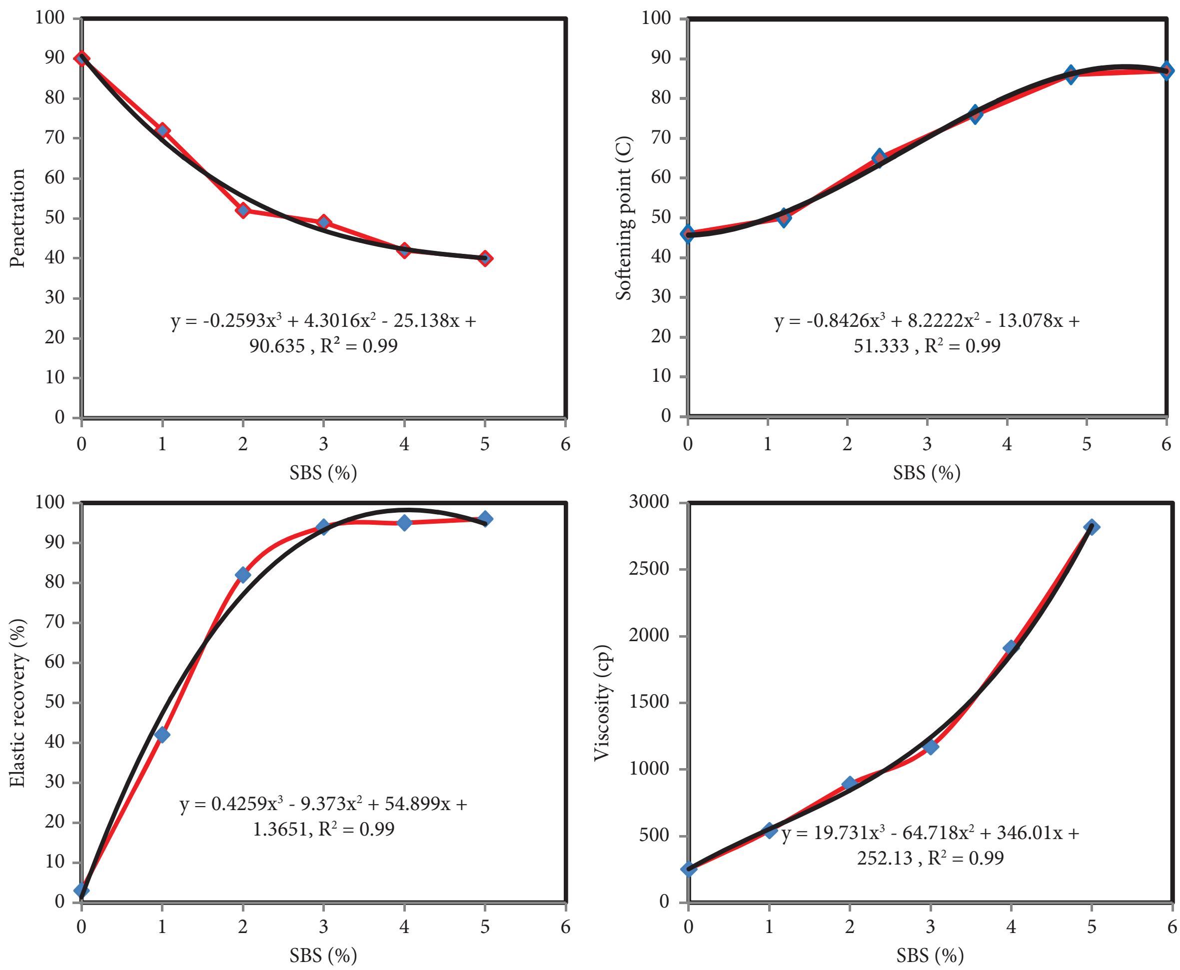

Figure 7: SBS percentage versus conventional test models.

The SBS 3% gave the PG value of PG76-16, which is suitable for nearly most of the hot countries' climate. Therefore, 3% of SBS is recommended as a suitable percent of using SBS content, considering climate and the available asphalt binder grade.

4.5. Aggregate and Asphalt Mixture. Prior to preparing asphalt concrete mixture, the necessary tests on aggregate were conducted. Table 8 shows the test results of the aggregate used for the asphalt mixture samples.

4.6. Aggregate Structure Selection. Five mixtures were prepared for each aggregate (A, B, and C) with five asphalt percentages (4, 4.5, 5, 5.5, and 6%) using asphalt grade 40/50 in order to select one of these three gradations, which can pass all of the required Superpave specifications. The procedures of mixing and compacting were conducted according to Superpave specifications using gyratory compacter.

The number of gyrations, density specifications, and D/B ratios are shown in Table 9. The sample diameter was 10 cm. The aggregate's maximum and nominal size were 19 and 12.5 mm, respectively. The aging times of the samples before compaction were 2 hours at 135°C.

Table 10 shows the calculations for the selected aggregate, which was aggregate B. The same calculations were carried out on aggregates A and C, where G_b is the specific gravity of the used asphalt, Ps % is the percent of solid particles (aggregate) in the mixture that is equal to 100 minus asphalt percent, D_{ini} is the density of sample during compaction at initial number of gyrations that is obtained from the gyratory compacter outcome, D_{ini} (%) is the density percentage compared to Gmm, and V_{ini} (%) is the air void percentage of the sample that is equal to 100 minus D_{ini} (%). Similarly, D_{des}, D_{des} (%), V_{des}, D_{max}, D_{max}(%), and V_{max} represent density, density %, and void % at design and maximum number of gyrations.

Vades (%), VMAdes (%), and VFA des% are the air void, void in mineral aggregate, and void filled with asphalt percentages at design numbers of gyrations calculated.

Pba % is the percentage of absorbed asphalt by aggregate, while Pbe% is the percentage of the effective asphalt in the mixture, which equals to AC% minus Pba%.

D/B is the dust (pass sieve no. 200) to binder ratio.

W_{air}, W_{water}, and W_{SSD} are the weight of sample in air, water, and saturated dry surface, which are used to find the bulk specific gravity of the sample mixture G_{mb}.

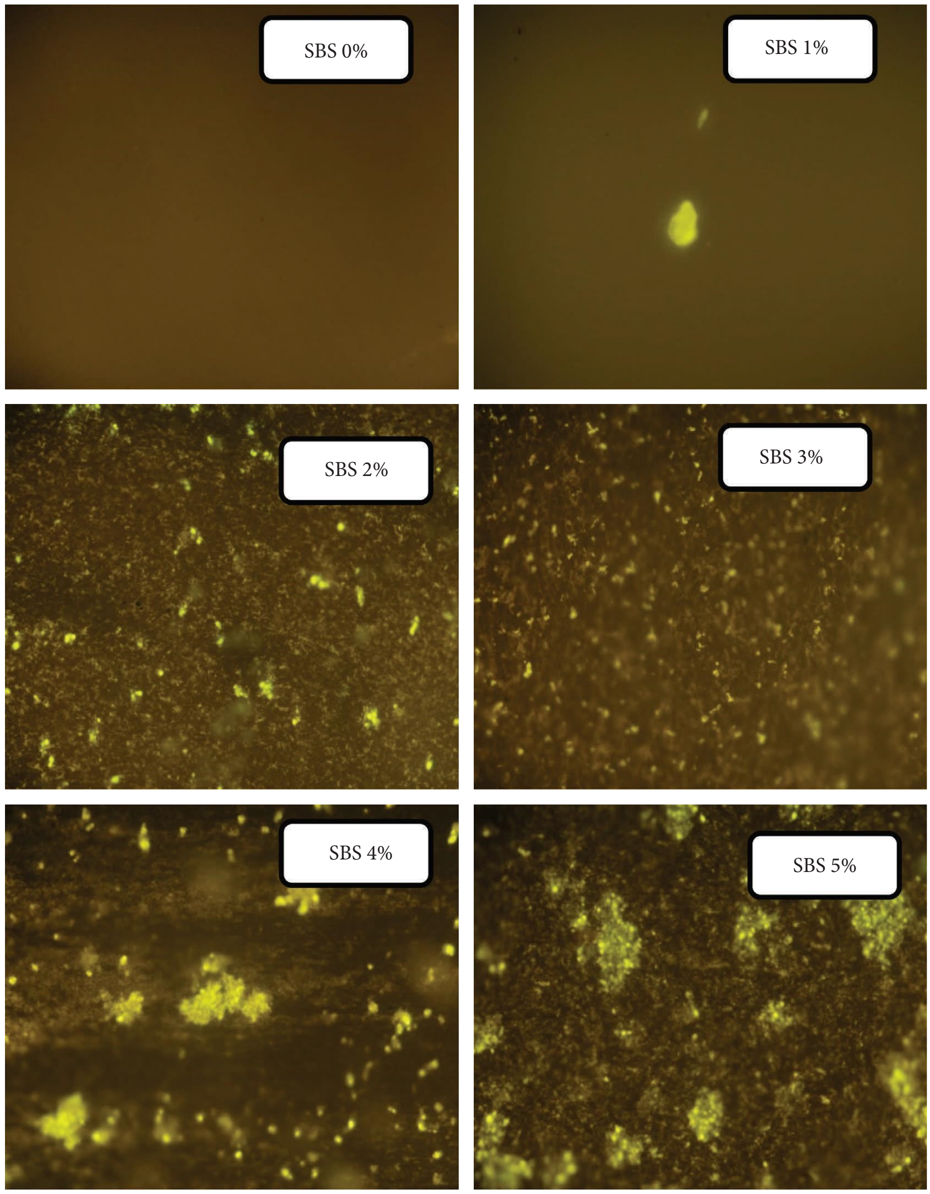

FIGURE 8: Fluorescent microscope images (40x) for SBS mixed with asphalt.

TABLE 5: DSR results for SBS asphalt binder samples.

Sample (%)	State	Temp. (°C)	$\delta°$	G^* (kPa)	$G^*/\sin\delta$ (kPa)	$G^*.\sin\delta$ (kPa)	Specification (kPa)	Result
SBS 0	Original	58	85.0	1.748	1.754		$G^*/\sin\delta \geq 1$	Pass
	RTFOT	64	79.7	3.728	3.789		$G^*/\sin\delta \geq 2.2$	Pass
	PAV	22	45.7	4987.246		3479.300	$G^*.\sin\delta \leq 5000$	Pass
SBS 1	Original	64	82.7	1.785	1.801		$G^*/\sin\delta \geq 1$	Pass
	RTFOT	70	76.1	3.866	3.985		$G^*/\sin\delta \geq 2.2$	Pass
	PAV	25	38.8	5386.722		3377.060	$G^*.\sin\delta \leq 5000$	Pass
SBS 2	Original	70	76.3	1.556	1.602		$G^*/\sin\delta \geq 1$	Pass
	RTFOT	82	70.8	2.401	2.542		$G^*/\sin\delta \geq 2.2$	Pass
	PAV	31	40.4	2476.727		1605.250	$G^*.\sin\delta \leq 5000$	Pass
SBS 3	Original	76	66.2	1.030	1.126		$G^*/\sin\delta \geq 1$	Pass
	RTFOT	88	73.7	2.164	2.254		$G^*/\sin\delta \geq 2.2$	Pass
	PAV	34	54.0	1680.571		1359.610	$G^*.\sin\delta \leq 5000$	Pass
SBS 4	Original	82	70.6	1.143	1.212		$G^*/\sin\delta \geq 1$	Pass
	RTFOT	88	69.9	2.396	2.551		$G^*/\sin\delta \geq 2.2$	Pass
	PAV	40	41.2	1242.237		817.930	$G^*.\sin\delta \leq 5000$	Pass
SBS 5	Original	94	48.0	1.122	1.508		$G^*/\sin\delta \geq 1$	Pass

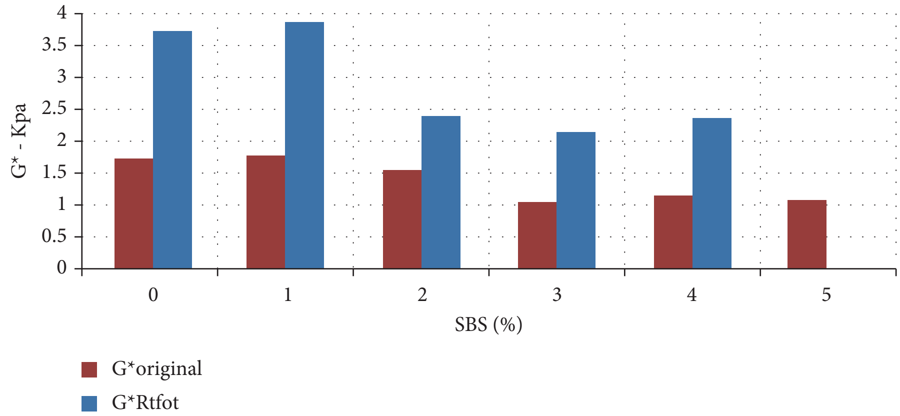

FIGURE 9: G^* values for original and RTFOT SBS samples.

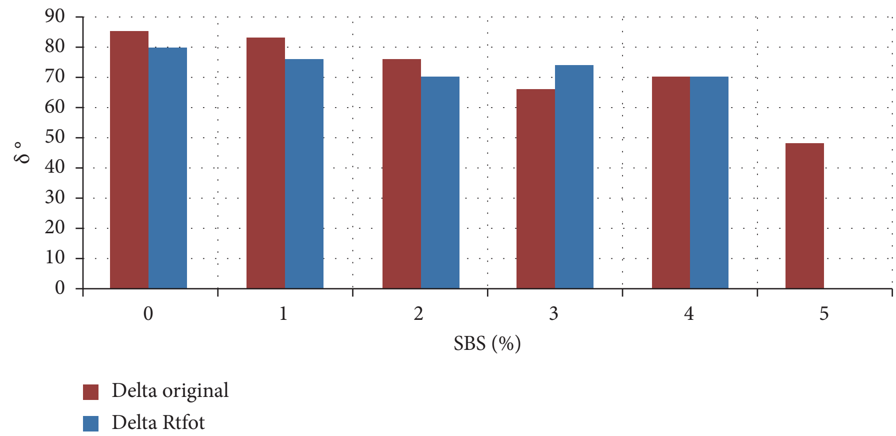

FIGURE 10: Delta values for original and RTFOT SBS samples.

TABLE 6: BBR results for asphalt mixture samples with different SBS percentages.

Sample (%)	Temp. (°C)	Stiffness (MPa)	m-value	Specification Stiffness (MPa)	Specification m-value	Result
SBS 0	−22	96.75	0.324	S max = 300	min. = 0.300	Pass
	−28	200.87	0.261			Fail
SBS 1	−22	121.96	0.303			Pass
	−28	245.24	0.253			Fail
SBS 2	−16	61.19	0.329			Pass
	−22	126.88	0.280			Fail
SBS 3	−16	64.92	0.316			Pass
	−22	128.33	0.275			Fail
SBS 4	−10	40.13	0.338			Pass
	−16	81.60	0.293			Fail

TABLE 7: PG results for asphalt mixtures with different SBS percentages.

No.	Asphalt (%)	DSR original	BBR	PG
1	SBS 0	58	−22	58-22
2	SBS 1	64	−22	64-22
3	SBS 2	70	−16	70-16
4	SBS 3	76	−16	76-16
5	SBS 4	82	−10	82-10
6	SBS 5	94	N/A	N/A

Table 8: Mixture test results.

Asphalt mixture			
Bulk specific gravity of aggregate (measured)	Gsb	2.584	Aggregate A
		2.595	Aggregate B
		2.605	Aggregate C
Maximum theoretical specific gravity of the mix	Gmm	2.434	Aggregate A
		2.440	Aggregate B
		2.446	Aggregate C
Effective specific gravity of aggregate (calculated)	Gse	2.615	Aggregate A
		2.623	Aggregate B
		2.629	Aggregate C

Table 9: Asphalt mixture specifications.

Equivalent single axle load (ESAL)	*N* initial	*N* design	*N* maximum
3 to < 30	8	100	160
Density specifications	≤89	96	≤98
D/B		0.8–1.6	

Table 10: Volumetric calculations for aggregate B.

AC (%)	4	4.5	5	5.5	6
Gsb	2.595	2.595	2.595	2.595	2.595
Gb	1.052	1.052	1.052	1.052	1.052
Gmm	2.475	2.458	2.440	2.424	2.407
Gse	2.623	2.623	2.623	2.623	2.623
Ps (%)	96.0	95.5	95.0	94.5	94.0
D_{ini}	2.031	2.043	2.068	2.108	2.156
D_{ini} (%)	82.06	83.12	84.75	86.96	89.57
V_{ini} (%)	17.94	16.88	15.25	13.04	10.43
D_{des}	2.275	2.315	2.354	2.387	2.393
D_{des} (%)	91.92	94.18	96.48	98.47	99.42
V_{des} (%)	8.08	5.82	3.52	1.53	0.58
D_{max}	2.314	2.355	2.386	2.403	2.406
D_{max} (%)	93.49	95.81	97.79	99.13	99.96
V_{max} (%)	6.51	4.19	2.21	0.87	0.04
Va des (%)	8.08	5.82	3.52	1.53	0.58
VMA des (%)	15.8	14.8	13.8	13.1	13.3
VFA des (%)	49.0	60.7	74.5	88.3	95.6
Pba (%)	0.43	0.43	0.43	0.43	0.43
Pbe (%)	3.58	4.09	4.59	5.09	5.59
D/B	1.67	1.47	1.31	1.18	1.07
W_{air}	1248.7	1252.5	1260.9	1265.9	1268.1
W_{water}	730.8	737.4	744.5	747.7	747.0
W_{SSD}	1257.8	1257.9	1263.7	1267.8	1269.5
Gmb	2.369	2.406	2.429	2.434	2.427

Figure 11 shows the volumetric analyses results of the curves for voids in design gyration (Va des), voids in mineral aggregate (VMA), density in initial gyration (D_{ini} (%)), void filled with asphalt (VFA), dust to binder ratio (D/B), and bulk specific gravity of the mix (Gmb).

The curves were drawn based on the data obtained from Table 10 and based on selecting 4% air voids in the mix (Va des) from the curve. From Figure 11, the optimum asphalt content for aggregate B was 4.9%. The other values can be obtained from the other curves according to the used asphalt percentages.

Table 11 shows the values that were obtained from Figure 11. *D* des and *D* max are taken from Table 10 by interpolation.

Comparing the results with Superpave specification, it was obvious that the aggregate B passed all the required specifications and was selected for all other asphalt mixtures.

To prepare the mixtures that were used for the ITSR and HWT tests for all SBS percentages, the same procedure of obtaining the optimum asphalt content was repeated for each case, as shown in Table 12.

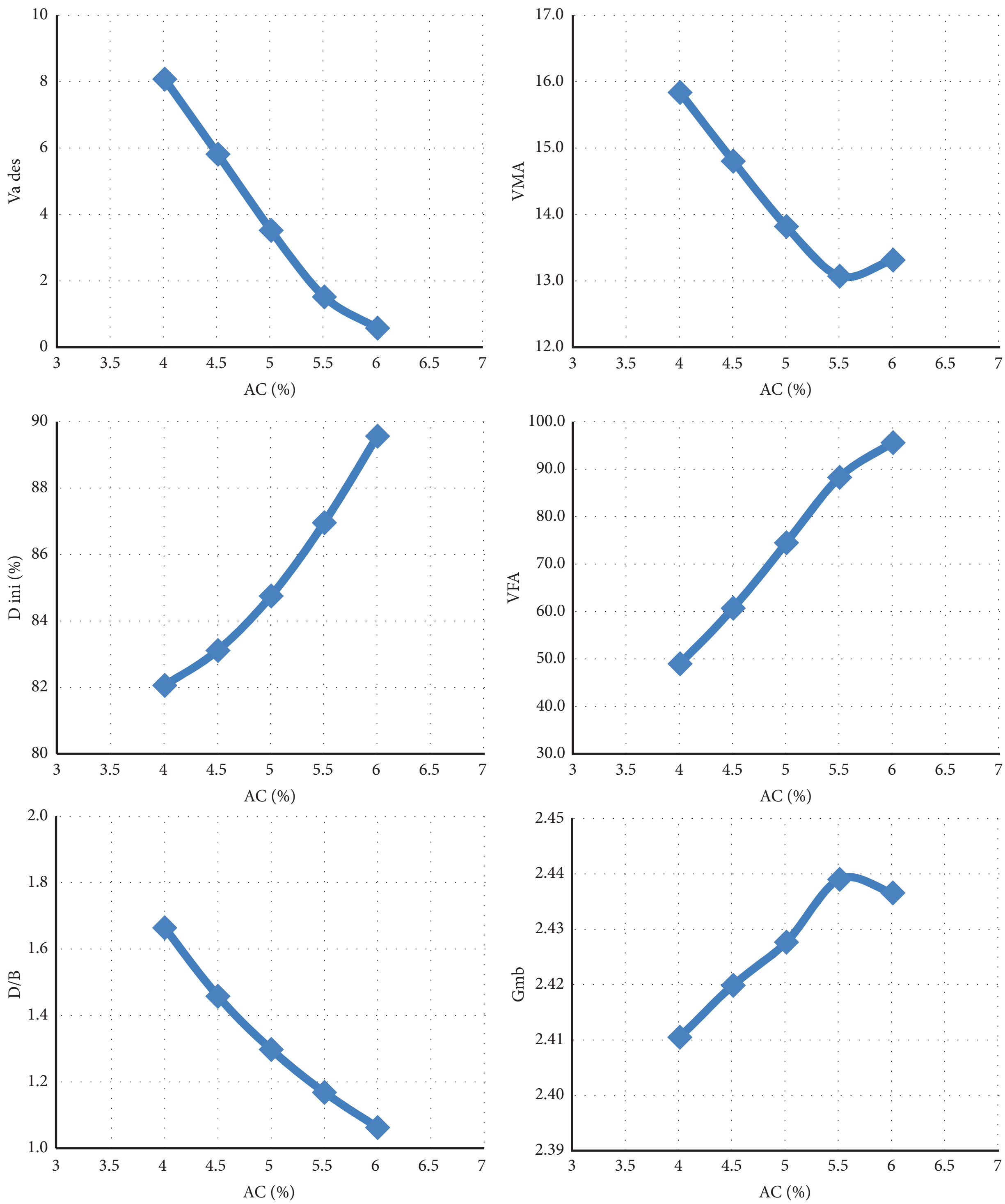

Figure 11: Volumetric analysis for aggregate B.

Table 11: Volumetric parameters for aggregate B.

Va	4%	Superpave specification	case
AC optimum	4.9		
VMA	14.0	≥14	Ok
VFA	71.7	65–75	Ok
D_{ini}	84.4	<89	Ok
D/B	1.34	0.8–1.6	Ok
D_{des}	96	96	Ok
D_{max}	97.4	<98	Ok
Gmb	2.425		

Table 12: Modified asphalt optimum content.

Additive (%)	Optimum (%)
SBS 0	4.9
SBS 1	5.1
SBS 2	4.85
SBS 3	4.75
SBS 4	5
SBS 5	4.9

4.7. ITSR Test Results. The ITSR test gives four important outcomes, which are as follows: dry tensile strength, conditioned tensile strength, tensile strength ratio between conditioned and unconditioned dry samples, and flow or deflection at failure. For severe environment, the conditioned strength and tensile strength ratios are more important than dry ones, while the deflection gives an indication on sample stiffness.

Table 13 presents the ITSR values for asphalt mixtures with and without using SBS. The degree of saturation (*S*) was kept between 70 and 75% to obtain homogeneous samples, while the Superpave specification value is between 55 and 80%. *S*% is the percent of volume of water to volume of air voids in the sample. The ITS is the indirect tensile strength load in kN, while *S* is the tensile strength divided by the area. The ITSR values increased with the increase in SBS% until the optimum additive percentage was reached, and then the ITSR values decreased. This trend is similar to the results obtained from the studies of the authors in references [14, 18]. The ITS and flow of dry samples for all SBS% were larger than those of the conditioned samples due to saturation effects.

Figure 12 shows the ITSR values for all asphalt mixtures with different percentages of SBS. The maximum value of ITSR was 97.6%, which was obtained at 3% of SBS. The ITSR is less than 80% for SBS 5%, which is out of Superpave specification due to the high percent of SBS. The ITS of dry sample is the highest at 4% SBS due to high gain in elasticity.

Figure 13 shows the indirect tensile strength of the conditioned samples that are more important than dry samples. It is clear that the higher tensile strength was recorded at the samples having 2 to 4% of SBS due to adequate presence of SBS.

4.8. HWT Test Results. The HWT test was conducted on two 15 cm diameter and 6 cm height samples for the mixtures prepared using modified asphalt with the SBS additives at the standard test temperature of 60°C. The test outcomes are number of passes versus rut depth in millimeter; then, a curve is drawn between the passes and rut depth to find the stripping inflection points (SIPs) and failure point (N_f).

SIP represents a point when the stripping occurs in the sample; before this point, the rut increases slowly, but after this point the increase rate is higher. The N_f point represents failure point when the sample reaches 20 mm rut depth.

Table 14 shows the results of HWT for the base sample and all the samples having different percentages of SBS. It is clear that the asphalt mixture with 3% of SBS had the best results regarding SIP and N_f. Also, the rutting resistance increased until the optimum percentage of the additives reached and then decreased. These results are similar to the conclusion in [19].

Figure 14 explains how SIP and N_f were obtained from the curve between number of passes and rut depth in millimeters for the asphalt mixture with 5% of SBS.

Although adding SBS additive material as a modifier to asphalt increases the construction cost of asphalt concrete by about 10%, the advantage of using SBS will be valuable

Table 13: ITSR results for asphalt mixtures with and without using SBS.

No.	Sample (%)	*S* (%)	TS (kN)	Flow	*S* (kPa)	TSR
1	SBS 0	73.9	5.697	3.03	577.9	80.3
2		73.8	5.431	2.65	551.9	
3		70.0	5.172	2.97	525.6	
4			6.990	2.00	711.1	
5			6.413	2.48	650.4	
6			6.873	2.32	699.0	
7	SBS 1	72.2	7.959	2.50	804.9	92.7
8		71.8	7.485	3.28	758.7	
9		74.2	7.327	2.77	746.1	
10			8.110	2.23	825.5	
11			8.269	1.71	837.6	
12			8.171	1.63	827.4	
13	SBS 2	73.4	10.617	2.81	1077.9	94.2
14		71.5	10.892	2.22	1099.5	
15		74.9	10.163	2.58	1036.4	
16			10.949	2.06	1109.3	
17			11.512	2.36	1164.9	
18			11.220	1.98	1137.9	
19	SBS 3	74.7	10.431	2.32	1057.5	97.6
20		73.7	10.621	2.52	1074.1	
21		72.4	10.984	2.23	1108.4	
22			10.902	1.72	1105.2	
23			11.172	1.04	1132.8	
24			10.633	2.01	1081.9	
25	SBS 4	72.3	10.498	2.61	1062.6	80.7
26		73.8	10.834	2.04	1093.7	
27		70.3	11.068	2.06	1120.7	
28			13.152	1.65	1322.9	
29			13.479	2.33	1364.8	
30			13.601	1.66	1374.9	
31	SBS 5	73.2	7.301	2.93	739.3	71.2
32		74.5	7.470	2.64	760.4	
33		72.8	6.939	2.48	704.3	
34			10.014	2.18	1012.1	
35			10.143	2.11	1037.5	
36			10.230	2.24	1043.7	

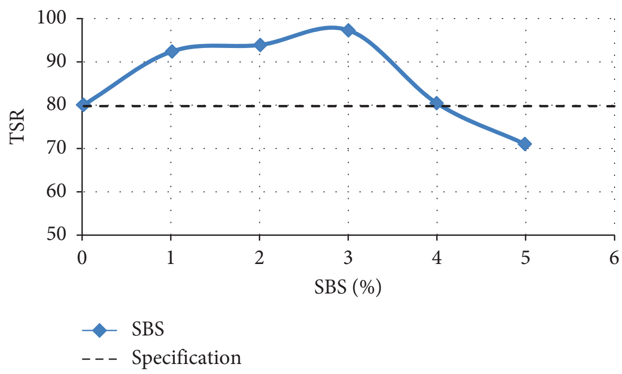

Figure 12: ITSR value for asphalt mixtures with different SBS percentages.

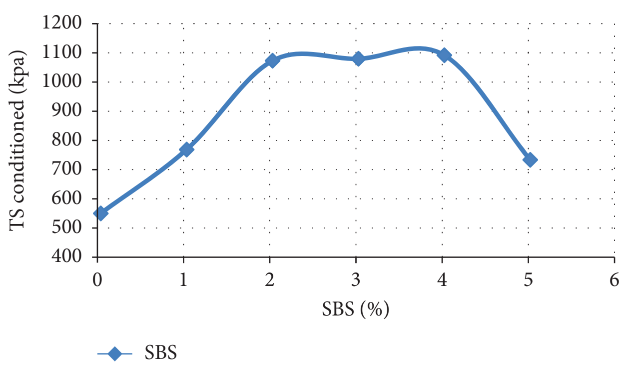

Figure 13: Conditioned tensile strength value for samples with different SBS percentages.

Table 14: Wheel tracker results for asphalt mixtures with different SBS percentages.

No.	Sample (%)	Cycles	Passes	SIP	N_f
1	SBS 0	1158	2316	800	2300
2	SBS 1	1893	3786	1500	3800
3	SBS 2	4900	9800	3100	9800
4	SBS 3	5791	11582	3600	10400
5	SBS 4	4556	9112	2900	8500
6	SBS 5	2540	5080	2500	5000

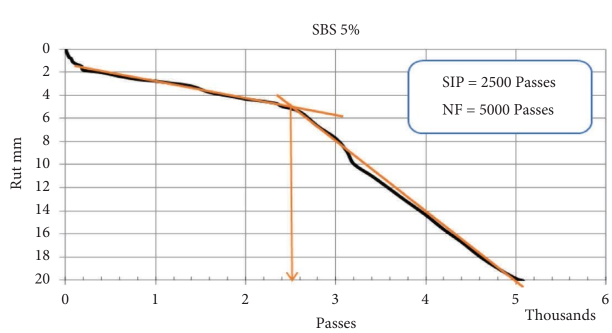

Figure 14: SIP and N_f for asphalt mixture with 5% of SBS.

regarding the improvement in engineering properties of the asphalt binders and mixtures and the reduction in future maintenance cost.

5. Conclusions

From the results of this study, the following conclusions can be obtained:

(1) Adding SBS to asphalt binder raises the viscosity value, which leads to higher mixing and compacting temperature of the asphalt concrete mixture, and this must be considered in the construction process.

(2) The optimum SBS percentage to get the best moisture and rutting resistance was at 3%, which is favorable for most hot and wet countries.

(3) The increase in ITSR from 80.3% of control sample to 97.6% of 3% SBS is 17.3%, which is a valuable amount in moisture resistance, while the increase in the rutting parameters of the control samples from SIP = 800, N_f = 2300 to SIP = 3600, and N_f = 10400 of 3% SBS is 350% for N_f and 352% for SIP. These are remarkable improvement in the rutting resistance of SBS asphalt concrete.

(4) Adding each 1% of SBS to asphalt binder will raise the high temperature PG by one grade, while adding each 2% SBS will raise low temperature PG by one grade. This insures that SBS improves high temperature PG clearly.

(5) The ITS of dry sample is the highest at 4% SBS, which is suitable for dry countries.

Data Availability

Compiled data and calculations are stored in Excel files in Highway lab/ civil department/College of Engineering/ University of Sulaimani and will be made available upon request to the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

Acknowledgments

The authors would like to thank the college of engineering, University of Sulaimani, for supporting this study.

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