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Qualitative Evaluation for Asphalt Binder Modified with SBS Polymer

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Abstract: Solutions for safer, more durable infrastructure are required in light of increasing traffic and severe weather in Iraq. The most significant road conservation and maintenance challenges are the pavement's low resistance to dynamic loads and short service life. As a result, vast sums of money are spent annually to enhance the road service capacities in Iraq. Thermoplastic electrometric polymers for bitumen modification create long-lasting, cost-effective roadways. This study aims to determine how the mechanical properties of neat asphalt binder change when styrene butadiene styrene (SBS) is added as a modifier. The current research investigates adding three percentages of SBS (3, 5, and 7% of the weight of bitumen). Both neat and polymer-modified bitumen (PMB) were subjected to a series of physical laboratory and Superpave tests, including a dynamic shear rheometer tester (DSR) and a storage stability test. In addition, a chemical analysis test was conducted to identify any change in the neat binder chemical composition due to the addition of SBS polymer. The results indicated that 5% of SBS polymer was the optimum addition percentage to the local asphalt in Iraq. Additionally, it reduced the susceptibility of bitumen to temperature changes and enhanced its characteristics in all laboratory tests. The obtained PMB significantly improved rutting and fatigue factors compared to the neat asphalt binder. Based on the DSR tester and the storage stability test, the ratio of 5% SBS met the requirements of class PG76-10, used in the central and southern governorates of Iraq. Using SBS polymer on the surface course in Iraq reduces road damage due to the scorching summer sun, reduces the likelihood of rutting and fatigue cracking, and works well in hot regions, resulting in roads that last longer, provide comfortable riding, and require less maintenance.

التقييم النوعي للإسفلت المحلي المعدل ببوليمر ستايرين -بيوتادين- ستايرين

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قسم هندسة الطرق والنقل/ كلية الهندسة / جامعة القادسية/ العراق.

الخلاصة

هناك حاجة إلى حلول لبنية تحتية أكثر أمانًا واستمرارية في ضوء زيادة حركة المرور والطقس القاسي في العراق. تتمثل أكبر التحديات في حماية الطرق وصيانتها في انخفاض مقاومة الرصيف للأحمال الديناميكية وقصر مدة خدمتها؛ ونتيجة لذلك، يتم إنفاق مبالغ ضخمة كل عام لتعزيز قدرات خدمات الطرق في العراق. تسمح البوليمرات الكهربية اللدنة الحرارية لتعديل البتيومين بإنشاء طرق طويلة الأمد وفعالة من حيث التكلفة. تهدف هذه الدراسة إلى معرفة كيف تتغير الخصائص الميكانيكية للإسفلت النقي عند إضافة بوليمر ستيرين-بيوتادين- ستيرين (SBS) كمعدّل. يتضمن البحث الحالي التحقيق في إضافة ثلاث نسب مئوية من SBS (٣, ٥, ٧ ٪ من وزن البيتومين). خضع كل من البيتومين النقي والمعدّل بالبوليمر (PMB) لسلسلة من الفحوصات المختبرية الفيزيائية والفحوصات الريولوجية Superpave، بما في ذلك اختبار مقياس القص الديناميكي (DSR) واختبار استقراريه التخزين. فضلاً عن إجراء اختبار تحليل كيميائي لتحديد أي تغيير في التركيب الكيميائي للمادة الرابطة النقية عند إضافة بوليمر SBS. أشارت النتائج إلى أن ٥٪ من بوليمر SBS هي النسبة المثلى للإضافة إلى الأسفلت المحلي في العراق. بالإضافة إلى ذلك، فهو يقلل من قابلية البيتومين للتغيرات في درجات الحرارة ويعزز خصائصه في جميع الفحوصات المختبرية. يتميز الأسفلت المعدل بالبوليمر PMB بمعامل جيد للتشقق والتخدد وهو أعلى بكثير من الأسفلت العادي. بناءً على فحص القص الديناميكي DSR واختبار استقراريه التخزينstorage stability، فإن نسبة ٥٪ تفي بمتطلبات الصنف PG76-10 المستخدم في المحافظات الوسطى والجنوبية من العراق. أثبتت النتائج أن استخدام بوليمر SBS في الطبقة السطحية في العراق يقلل من الأضرار التي تحدث على الطرق بسبب شمس الصيف الحارقة، ويقلل من احتمالية التشقق والتخدد، ويعمل بشكل جيد في المناطق الحارة، مما ينتج عنه طرق تدوم لفترة أطول، وتوفر قيادة مريحة، وتتطلب صيانة أقل.

الكلمات الدالة: مقياس القص الديناميكي، مطياف الأشعة تحت الحمراء، مؤشر الاختراق، درجة الأداء، البيتومين المعدل بالبوليمر، ستايرين-بيوتادين- ستايرين.

1.INTRODUCTION

Asphalt is a residual leftover after crude oil refining. It is a combination of several different chemical components. Asphalt is a well-known natural substance commonly employed in road pavement construction as a binder for aggregates in asphalt mixes [1, 2]. Asphalt materials are utilized worldwide for both roadway construction and roofing. More than 90% of motorways throughout the globe use asphalt pavement, which is compacted using an asphalt mixture made up of about 95 percent mineral aggregates and 5 percent bitumen binder [3]. The chemical composition of asphalt cement changes somewhat depending on the crude oil origin. Although hydrogen and carbon comprise most of the composition, sulfur and heavy metals are essential contributors to asphalt cement's physicochemical characteristics[4]. The increase in traffic volumes over the last several years has fueled tremendous growth in the highway pavement construction sector globally [5, 6]. The practical needs of modern and future highway pavement construction are difficult to satisfy with conventional paving materials. Therefore, there is a critical need for pavement materials with a higher standard in terms of quality, safety, reliability, and environmental sustainability [7, 8]. The development of an asphalt roadway that is both long-lasting and environmentally friendly is of crucial importance to the fields of material science and road engineering. Over the last ten years, there has been a discernible growth in the research conducted on asphalt materials, leading to the publication of several articles. In recent years, significant progress has been made in both the design and technology of bituminous materials and pavement evaluation. Different methods of modification and application have been developed to enhance the quality of asphalt materials and increase the pavement's service life [3, 9]. Several polymers are utilized as modifiers for bitumen to enhance road construction and address problems caused by high temperatures and heavy traffic loads. Thermoplastic elastomeric polymers account for the majority of the polymers used. Styrene butadiene styrene (SBS) polymer is one of these types, which is suitable for modifying traditional asphalt as it is widely available [10]. Many studies are concerned with modifying asphalt binders with SBS polymer; Sengoz and Isikyakar [11] evaluated the properties and microstructure of polymer-modified bitumen. The content of the SBS polymer used in the study was (2, 3, 4, 5, 6, and 7% by weight of the asphalt binder). The results showed that the morphology of the polymer-modified bitumen depended on the polymer content in the asphalt as well as the nature and source of the polymer. In addition, the conventional tests of the polymer-modified bitumen showed an increase in stiffness (hardness), temperature susceptibility improvement, and Marshall stability. The optimum SBS content was 5% for all tests. Singh et al. [12] studied the characteristics of SBS as a modifier of neat asphalt by examining three percentages (3, 5, and 7% of SBS by weight of neat asphalt). The result of the experimental tests showed that the asphalt modified with SBS has higher rutting and fatigue factors than the control asphalt. Al-Azawee and Latief [13] conducted several laboratory tests, such as a rotational viscometer, penetration test, and softening point test, on conventional asphalt modified with 4, 4.5, and 5% SBS. The results revealed that adding SBS to ordinary bitumen improved the asphalt's mechanical properties, as it reduced penetration and improved the softening point, increasing the viscosity. Furthermore, incorporating SBS in the bitumen decreased its temperature susceptibility, as can be observed from the enhancement in the penetration index. Several studies have found that SBS polymer improves the durability of asphalt binder against rutting in hot weather and fatigue cracking in cold weather [14, 15]. Excellent laboratory performance and durability of SBS-modified asphalt have led to its widespread use in road engineering [16]. According to data obtained using Fourier transform infrared polymer spectroscopy (FTIR), adding SBS resulted in new polar functional groups in asphalt, contributing to the material's improved elasticity even when exposed to high temperatures [17, 18]. Although different asphalt types can be assigned to the same grading according to penetration and viscosity specifications, in practice, such asphalt performs differently and reaches different temperatures. The Strategic Highway Research Program (SHRP) produced performance tests and requirements for Hot Mix Asphalt (HMA) and asphalt binders called "Superior Performing Asphalt Pavements" (Superpave). The design and analysis of the HMA are enhanced by adopting Superpave technology. Additionally, SHRP research produced asphalt tests and performance-graded (PG) specifications [19]. The climate in which the pavement will be utilized is a major factor in choosing the asphalt PG. Different asphalt grades must be used depending on whether the pavement temperature is high or low [20]. A geographic information system (GIS) was used to create a map of Iraqi climate zones in terms of asphalt PG. According to Fig.1, PG76-10 and PG70-10 cover more than 70% of Iraq. Iraq is one of the countries that have long, hot summers and cold winters, as can be seen in Fig.2, which depicts the field measurements for the pavement surface temperature. Accordingly, as the temperature increases, asphalt begins losing its useful characteristics, which causes significant damage to HMA. This damage increases with an increase in the traffic volume and axle load. Consequently, polymers must be used to improve neat asphalt binder. The main objective of this research is to provide a qualitative assessment of the effectiveness of thermoplastic electrometric polymers (such as SBS) in enhancing asphalt binders. This assessment was carried out through a series of controlled laboratory experiments, which are very limited in use in Iraq, including Dynamic Shear Rheometer (DSR) and storage stability testing. These tests and some chemical tests gave a clear idea of the rheological characteristics and PG of both neat and PMB.

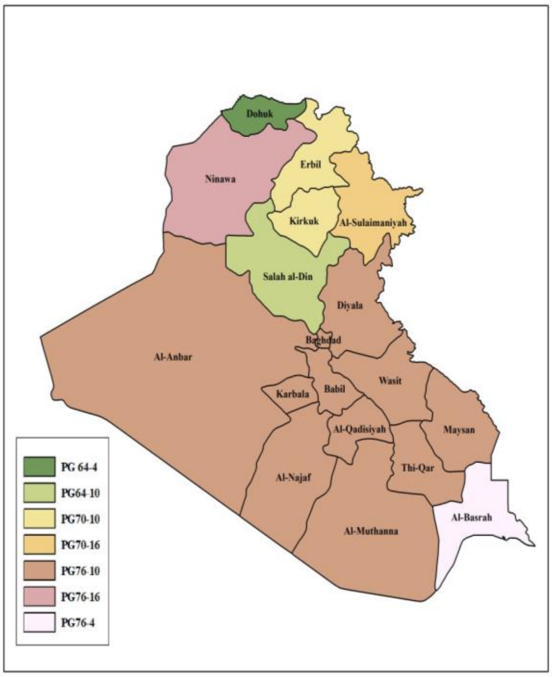

Fig. 1 Temperature Zones for Iraqi Asphalt Binder Requirements, Based on the Data of the Ministry of Construction, Housing, Municipalities, and Public Works.

Fig. 2 The Field Measurements at Highway no.1 Connecting between the Governorates of Al-Diwaniyah and Dhi Qar.

2.MATERIALS AND EXPERIMENTAL PROCEDURE

2.1.Bitumen Binder

Traditional asphalt cement with a penetration grade of 40-50 was supplied from the Al-Nasiriyah refinery in southeast Iraq. This asphalt cement is widely used as a binder for HMA. The essential laboratory testing for this binder was conducted in line with the appropriate ASTM standards, and the results were analyzed in light of the criteria established by the State Corporation for Roads and Bridges (SCRB,2003) [21]. Fig. 3 and Table 1 show these tests and their results.

Table 1 The Physical Characteristics of Neat Bitumen.

Test Type	Standard (ASTM)	Test Value	SCRB limit
Penetration at 25 °C (0.1 mm)	ASTM-D5[22]	43	40-50
Softening point (R&B°C)	ASTM-D36[23]	52	---
Ductility at 25 °C (cm)	ASTM-D113[24]	115	>100
Flashpoint (°C)	ASTM-D92[25]	300	>232
Apparent Viscosity at 135°C (Cs)	ASTM-D4402[26]	628	>400
Solubility in trichloroethylene (%)	ASTM-D2042[27]	99.79	>99
Specific Gravity at 25°C (gm/cm³)	ASTM-D70[28]	1.039	---
Dynamic Viscosity at 60°C (Pa. s)	ASTM-D88[29]	485	---
Kinematic Viscosity at 60°C (Cs)	ASTM-D88[29]	476	---

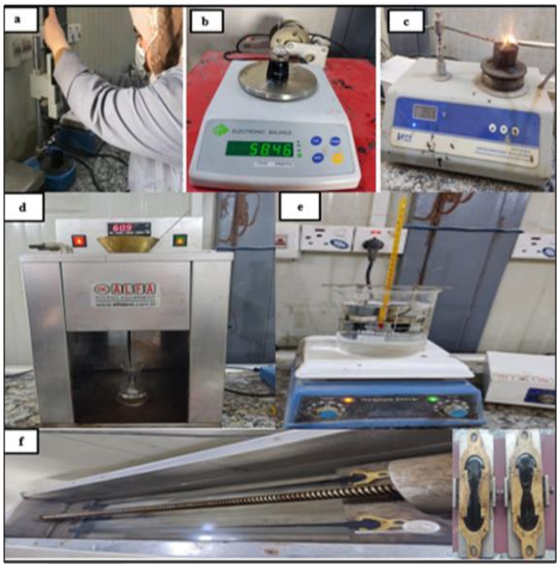

Fig. 3 (a) Penetration Test, (b) Specific Gravity Test, (c) Flashpoint Test, (d) Saybolt Viscometer, (e) Softening Point Test, (f) Ductility Test, An Experimental Tests of Asphalt Binder.

2.2.SBS Modifier

SBS Kraton type D1101, supplied by a Kraton polymer company, was used as a modifier for bitumen in this study. SBS was added in three different percentages: 3%, 5%, and 7% (by weight of neat bitumen). SBS comes in small white granules that are easily spread in neat asphalt, as shown in Fig. 4. Fine SBS granules are encased in the bitumen by aromatic components that are linked to one another through sulfide or polysulfide bonds, forming polymer-bitumen chain connections. These Sulfur bonds not only contribute to the improvement of polymer compatibility with bitumen, but they also have the potential to alter the rheological characteristics of the binder. This potential effect is contingent on the cross-link density and bonding lengths [30]. The chemical chain forming the SBS (see Figs. 5 and 6) comprises two parts: styrene, a solid plastic that adds to asphalt's resilience at high temperatures, and butadiene, which represents rubber and contributes to asphalt's flexibility at low temperatures [31, 32].

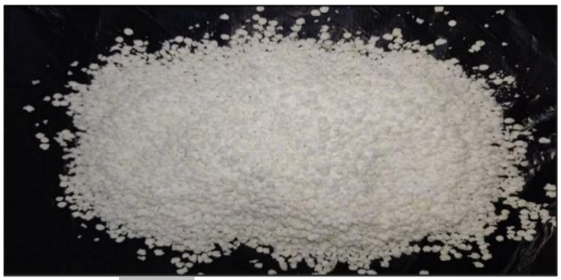

Fig. 4 SBS Particles Shape.

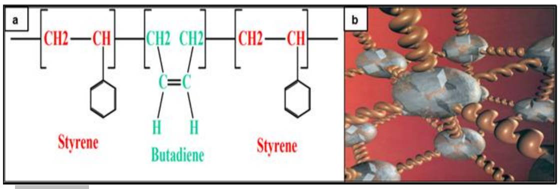

Fig. 5 Bonding of SBS Modifiers in Bitumen: (a) SBS Chemically Form (b) A schematic Showing the SBS Copolymer [30].

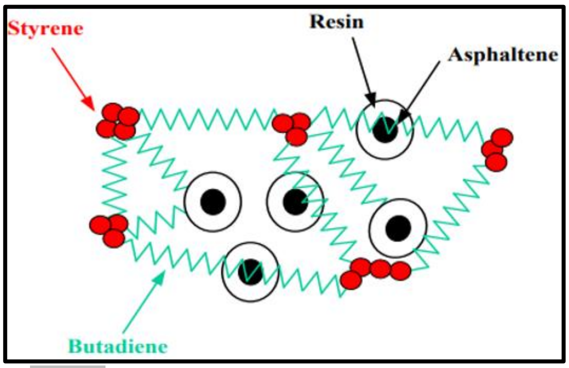

Fig. 6 The Connection of the SBS Polymer with the Asphalt Cement [31].

2.3.FTIR (Fourier Transform Infrared) Analysis

FTIR analysis is a measuring method based on the idea that the molecules that comprise a substance's molecular structure receive power or irradiation of a specific wavenumber [33]. The FTIR spectrometer has seen widespread use in medicine, science, and engineering, all of which are concerned with studying chemical interactions and determining the structure of particles because it is more informative than other diagnostic methods to identify the molecules' structure [34, 35]. In the case of bitumen, around 90 % of the substance comprises a mixture of carbon and hydrogen. Its shape is determined by the degree to which it has been oxidized, and an FTIR test may be performed to identify its structure and any changes that may occur due to the use of SBS [36, 37]. The interaction between the modifier and bitumen is critical in explaining the modifier's modification mechanism on bitumen [38]. A chemical reaction may be reflected in the FTIR spectrum by peak (functional group) variations. The TENSOR 27 FITR spectrometer from Bruker Corporation was used in the present study to get the spectra of neat bitumen and PMB. Each sample was scanned a total of ten times. For analysis, a wavenumber of 4000 cm^{-1} to 500 cm^{-1} was used in this test. Furthermore, the transmission peaks of base bitumen and PMB were compared. The resulting spectrum was then analyzed to determine the chemical composition of the samples. Fig. 7 shows the FTIR equipment test.

Fig. 7 FTIR Equipment Test.

2.4.Laboratory Tests

Traditional tests were performed on both neat and polymer-modified bitumen (see Fig. 8). These tests included a penetration test, a softening point test, a viscosity test, a toughness test, a tenacity test, and a Superpave test, which included the DSR and storage stability tests. To mix control asphalt cement with SBS, firstly, the asphalt was heated in the oven at 160 °C for one hour. Secondly, it was put in a high-shear mixer, and SBS was added gradually according to the specified proportions (3, 5, and 7% by weight of the neat asphalt) to avoid agglomeration. Thirdly, it was mixed with a high-shear mixer at a speed of 3000 revolutions per minute and a temperature of 180 °C. Finally, it was put in an oven for four hours at a temperature of 160 °C to achieve the curing process, complete the homogeneity of the mixture, and avoid separation. Then, it was returned to the mixer and mixed for one hour at a temperature of 180 °C. Fig. 9 shows the mixing machine for SBS and asphalt binder.

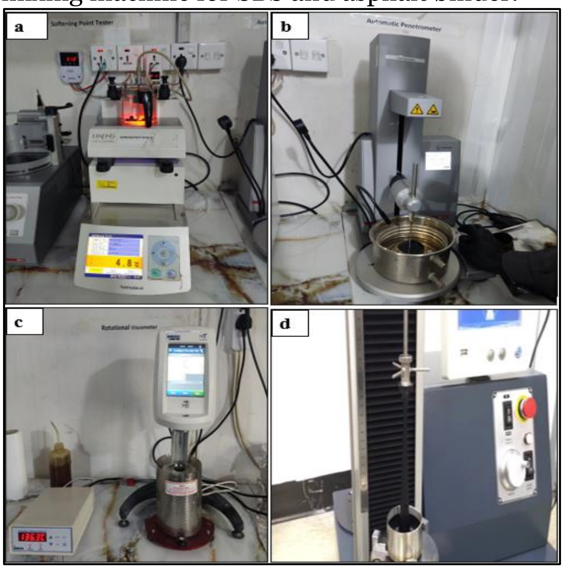

Fig .8 Experimental Tests of PMB: (a) Automatic Softening Point Tester, (b) Automatic Penetrometer Tester, (c) Rotational Viscometer Test, (d) Toughness and Tenacity Test.

Fig.9 High Shear Mix Machine.

3.RESULTS AND DISCUSSION

3.1.Penetration Test

The penetration test was carried out according to the requirements described in ASTM D5 [22]. This test's primary objective is to determine the level of consistency and stability present. Additionally, it determines whether bitumen has a hard or soft texture. Penetration tests were performed for neat and modified bitumen containing 3%, 5%, and 7% SBS by bitumen weight. The results are depicted in Fig. 10, illustrating how an increase in SBS content led to a lower penetration value up to a critical concentration of around 5% SBS. The modifier became the major matrix and formed a continuous film around the neat asphalt binder droplets when the concentration reached 5%. So, it seems that 5% SBS was the best concentration because the penetration value started to decrease as the modifier proportion went up. These results agree with previous work in the literature [12].

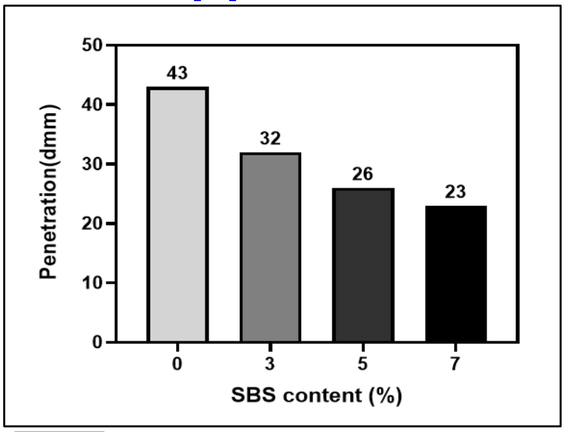

Fig .10 Penetration Test Results of Neat and PMB with SBS.

3.2.Softening Point Test

The softening point measures the bitumen's consistency and defines the characteristics of the binder at elevated temperatures. When the softening point increases, a material is classified as less susceptible to temperature change and, therefore, more resistant to some distress, such as permanent deformation. The softening point was tested using standards established by ASTM D36 [23]. Fig. 11 shows that the softening point increased with the ratio of SBS modifiers. The bitumen's softening point increased with its viscosity due to increased asphaltene concentration. When 7% SBS was added, the bitumen's softening point increased from 52.0 to 78.0 °C. This increase in softening points due to higher polymer swelling from increased modifier concentration led to a rise in asphaltene content due to the polymer phase's absorption of maltene, creating a stiffer matrix.

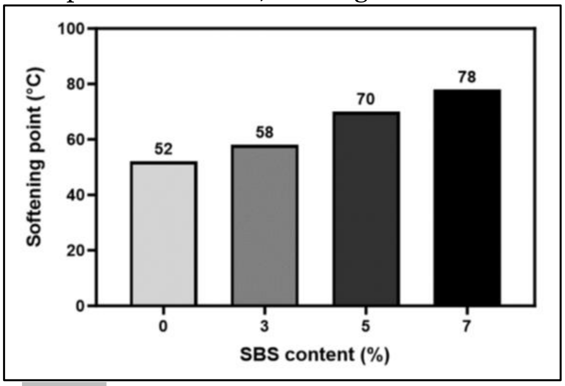

Fig .11 Softening Point Values for Neat and PMB with SBS.

3.3.Toughness and Tenacity Test

Tenacity is the total effort required, while toughness is the force required to release the sample from the tension hand. Tenacity measures the force that continues to increase when a sample is stretched beyond its original peak [30]. This test was conducted by the ASTM D5801 standards [39]. Although data for toughness and tenacity may be produced for any kind of polymer-modified or non-modified asphalt, the testing procedure is most often employed to characterize elastomer-modified asphalts. This testing technique helps to establish that asphalt cement has been changed with a substance that supplies a large amount of an elastomeric component. The ability of SBS-modified asphalts to resist extensive elongation before cracking is one of the properties that may be utilized to distinguish them from conventional asphalts. The tenacity and toughness tests of the asphalt binder serve as gauges for this ability. It can be observed from Fig. 12 that the more SBS there is, the more effort is required to extend PMB. The characteristics of the base asphalts impact toughness and tenacity, suggesting that mixing different grades of bitumen with SBS might result in varying degrees of engineering properties. At 5% SBS, hardness and tenacity were at their highest levels. After reaching a peak, hardness and tenacity gradually declined, suggesting that mixing in more than 5% SBS might cause a morphological discontinuity between the SBS and the asphalt. Incompatibility between SBS and asphalt is to blame for this break in continuity. The tenacity test is an effective means of gauging the SBS polymer's robustness. The results also indicated that the greatest value was 5%. Adding the SBS modifier increased the basic bitumen's tenacity and resistance to breaking, as observed in the literature [40].

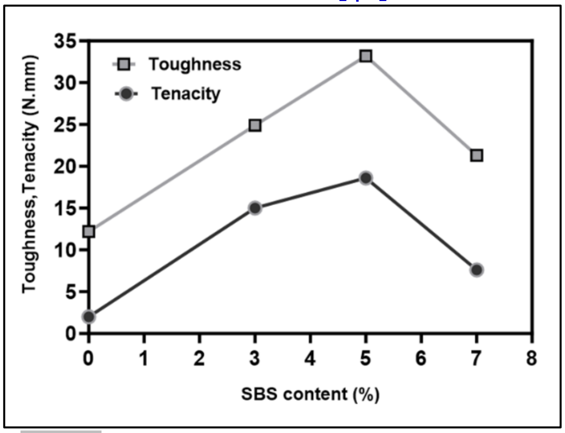

Fig.12 Toughness and Tenacity of Neat and PMB with SBS.

3.4.Rotational Viscometer Test

The rotational viscometer test was conducted using a viscometer to determine the asphalt's apparent viscosity at high temperatures. To reduce the amount of power required for the asphalt plant's mixing, laying, and compacting processes, the PMB must stay fluid or workable during the production and construction process of HMA. Viscosity was measured using a rotating viscometer to see how well-modified asphalt mixes and compacts. This test complied with the specifications given in ASTM D4402 [26]. Using a Brookfield viscometer with a thermos container for temperature control, dynamic viscosity was measured for the produced samples at 135 °C [1, 41]. At 135 °C, bitumen had a viscosity of 628 Cs. As the percentage of SBS polymers was raised from 3% to 5% to 7%, the viscosity of bitumen increased from 1110 Cs to 1795 Cs to 2300 Cs, respectively. This increase is because when a suitable elastomer (like SBS) is put into bitumen, the bitumen's oily component is absorbed by the polymer, which causes it to expand (typically up to eight times its initial volume). This physical process might be affected by factors such as time, production technique, or additives [32, 42, 43]. As shown in Fig. 13, when SBS was added to the plain asphalt binder, the binder's viscosity increased dramatically. This behavior is attributed to the interaction of SBS with asphaltene in the asphalt binder. Increasing the viscosity to a very high value is not recommended in asphalt factories because it requires power to heat the modified asphalt, and the high viscosity cannot be pumped through pipes. The viscosity of PMB with 5% SBS was more suitable for mixing in asphalt plants in Iraq.

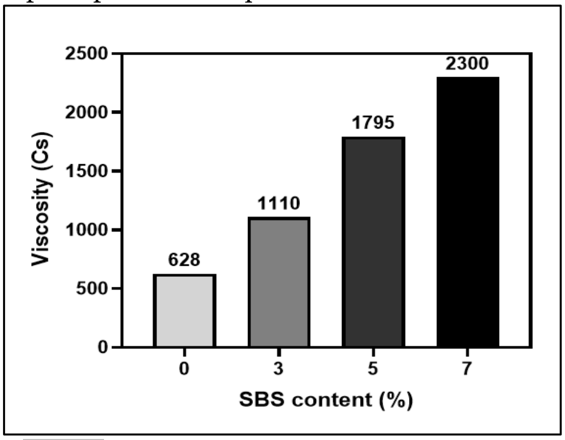

Fig.13 The Viscosity of Neat and PMB with SBS.

3.5.The Temperature Susceptibility

The temperature susceptibility of asphalt binder is considered a significant rheological feature, particularly for PMB since it is connected to its ability to resist permanent deformation. Temperature susceptibility describes how quickly the characteristics of asphalt binders vary with temperature, as measured by parameters, including penetration index (PI) and penetration viscosity number (PVN) [44]. The PI and PVN are numerical indicators of the asphalt bitumen sensitivity to temperature changes. Knowing the PI and PVI of a certain bitumen allows one to predict its behavior in a given application. As a consequence, asphalt binders with a high penetration number (known as "soft") are used in cold regions, while those with a low penetration number (known as "hard") are used in hot temperatures. All bitumens have thermoplastic properties, which means they soften when heated and stiffen when cooled [45]. Asphalt cement's susceptibility to a reduction in temperature is reflected in increased PI values. Standard asphalt cement has a PI in the range of -2 to +2. The temperature susceptibility indicator values were derived from the results of the softening point and penetration tests. Eq. (1) is a common method of calculating PI [30]. In addition to the PI, McLeod (1976) also introduced Eq. (2), which determines PVN using normal paving asphalt characteristics [46]. PVN determination is based on the penetration and viscosity at 25°C and 135°C, respectively. A high PVN indicates low thermal susceptibility, while a low PVN indicates high thermal susceptibility. When both the PI and PVN are low, the bitumen is more susceptible to temperature [46]. Fig. 14 illustrates the PI and PVN values of both neat and PMP.

$$PI=[1952-500\times logpen-20\times sp]/[50\times logpen-sp-120] \quad \textbf{(1)}$$

$$PVN= [\log L-\log X]/ [\log L-\log M] \times (-1.5) \quad \textbf{(2)}$$

where P and SP represent the values of penetration and softening point, respectively. X =log viscosity in Cs at 135 °C; L = 4.25800–0.79670 log pen at 25 °C; and M = 3.46289–0.61094 log pen at 25 °C. According to the findings in Fig.14, adding SBS to 40-50 penetration grade bitumen binder provided the highest value of PI (2.22) while simultaneously achieving the highest possible value of PVN (0.47). The results showed that the SBS reduced the temperature susceptibility of asphalt binder, improving the performance of HMA.

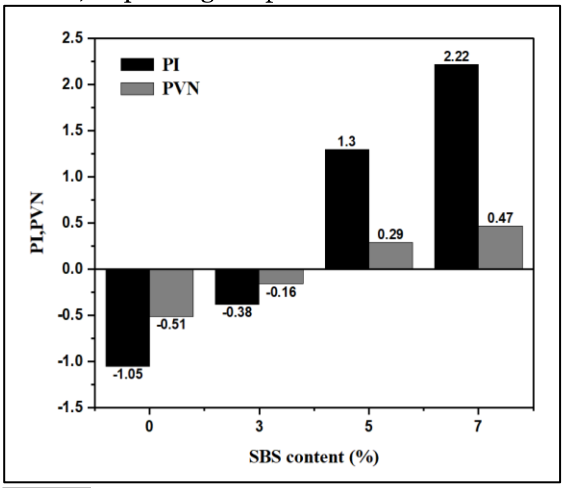

Fig. 14 PI and PVN of Neat and PMB with SBS.

3.6.Dynamic Shear Rheometer (DSR)

The DSR test is used to study the viscous and elastic characteristics of asphalt binders between moderate and high temperatures (see Fig. 15). The temperatures utilized in this test are based on the prevalent climate conditions in the region where the asphalt binder will be constructed.

Fig.15 The DSR Device.

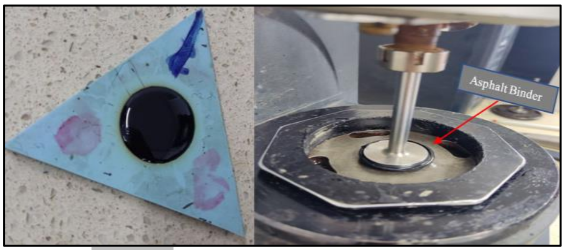

Fig.16 Sample of the DSR Test.

DSR primarily measures the complex shear modulus (G*) and the phase angle (δ) to get viscoelastic characteristics. The first parameter, known as G*, the ratio of the highest shear stress to its greatest shear strain, measures the overall resistance to deformation under shear loading. The second parameter is phase angle (δ), which indicates the degree of elasticity of the asphalt binder [47]. Both parameters were measured at high and moderate temperatures to identify permanent deformations and fatigue cracking. In the first stages of a pavement's existence, rutting is the primary cause of worry, but fatigue cracking becomes the primary cause of concern as the pavement ages. To prevent permanent deformation, G */sin δ must be kept above 1.0 kPa in its original state (before aging). This study tested conventional asphalt cement with 40-50 penetration with three different ratios of modified asphalt with SBS modifiers for the original case. The resulting sinusoidal shear stress was monitored and evaluated as a function of both temperature and frequency. The complex shear modulus and phase angle were calculated using various temperatures. A temperature range of 64 to 94 °C was employed for the experiments, as displayed in Tables 2–5. The basic DSR test uses a thin asphalt binder sample of 0.04 inches (1 mm) in thickness and 1 inch (25 mm) in diameter sandwiched between two circular plates. The lower plate is fixed while the upper plate oscillates back and forth across the sample at 10 rad/sec (1.59 Hz) to create a shearing action (see Fig. 16). The gap width was adopted as 1mm, and the measurements were carried out at a frequency of 10 rad/s by AASHTO T 315 [48].

Table 2 Summary of the DSR Outcomes of Neat Asphalt.

No.	**1**	**2**	**3**
Result	Pass	Pass	Fail
Temperature (°C)	64	70	76
Phase Angle δ (°)	83.9	82.3	79.0
Complex Modulus G* (kPa)	2.87	1.43	0.873
G*/Sin δ (kPa)	2.89	1.44	0.889
Shear Stress (Pa)	346.855	170.465	103.922
Frequency (rad/sec)	10.03	10.03	10.03

Table 3 Summary of the DSR Outcomes of 3% SBS Modifier

No.	**1**	**2**	**3**	**4**
Result	Pass	Pass	Pass	Fail
Temperature (°C)	64	70	76	82
Phase Angle δ (°)	75.2	73.6	72.1	68.8
Complex Modulus G* (kPa)	6.91	2.26	1.35	0.78
G*/Sin δ (kPa)	7.1387	2.3587	1.4176	0.8365
Shear Stress (Pa)	403.476	227.086	160.543	94.00
Frequency (rad/sec)	10.03	10.03	10.03	10.03

Table 4 Summary of the DSR Outcomes of 5% SBS Modifier.

No.	**1**	**2**	**3**	**4**	**5**	**6**
Result	Pass	Pass	Pass	Pass	Pass	Fail
Temperature (°C)	64	70	76	82	88	94
Phase Angle δ (°)	59.8	59.0	57.5	56.0	55.5	55.0
Complex Modulus G* (kPa)	11.4	6.62	4.08	2.62	1.46	0.62
G*/Sin δ (kPa)	13.2	7.72	4.84	3.17	1.77	0.76
Shear Stress (Pa)	1383.91	789.635	491.173	316.0	175.173	140.827
Frequency (rad/sec)	10.03	10.03	10.03	10.03	10.03	10.03

Table 5 Summary of the DSR Outcomes of 7% SBS Modifier.

No.	**1**	**2**	**3**	**4**	**5**	**6**
Result	Pass	Pass	Pass	Pass	Pass	Fail
Temperature (°C)	64	70	76	82	88	94
Phase Angle δ (°)	54.2	52.9	51.4	50.0	48.7	47.4
Complex Modulus G* (kPa)	15.8	7.80	5.26	2.45	1.50	0.71
G*/Sin δ (kPa)	19.48	9.78	6.73	3.204	1.998	0.963
Shear Stress (Pa)	1492.83	898.555	600.093	424.92	284.234	159.590
Frequency (rad/sec)	10.03	10.03	10.03	10.03	10.03	10.03

Neat and PMB were tested by measuring their G* and δ at various temperatures. It can be observed from Table 2 that the neat asphalt fails at 76 °C. Hence, this indicates that the local bitumen supplied from Dhi Qar is not compatible with the required PG in the central and southern regions of Iraq; therefore, it fails and is exposed to rutting and fatigue cracking because the G*/Sin δ is equal to 0.889, which is less than the requirements of class 76-10, which requires a DSR value of 1 KPA as a maximum at the original state. It can be noted from Fig. 17 that with the increase in the percentage of additive, the complex shear modulus (G*) increased and the phase angle (δ) decreased compared to control asphalt. The reason for the increase in G* is that the additive makes the bitumen hard and thus increases its resistance to deformation. The reason for the decrease in the phase angle values indicates a transition from viscoelastic to elastic behavior. The polymer works to increase the elastic properties, so the phase angle decreases compared to neat asphalt. This is considered a remarkable indicator to reduce the permanent deformation that occurs in the asphalt binder as a result of the applied stress, according to several findings in previous studies [47, 49, 50]. Regarding the SBS-PMB, it was observed from Tables 3-5 that the DSR coefficients G*/sinδ increase with the SBS percentage increases. This notable increase in G* after 5% SBS demonstrates the creation of a polymer network within the binder. As shown in Figs. 18 and 19, the rutting and fatigue resistance of SBS-modified asphalt rose dramatically with increasing SBS modifier concentration due to the modifier's elastomer phase absorbing the bitumen oil component, causing an increase in the stiffness of bitumen. The asphalt binder's permanent deformation resistance (expressed as G*/sinδ) would increase with the addition of SBS. Also, SBS increases the resistance against fatigue stresses represented by (G*× sinδ), so it increases the resistance of HMA to the traffic loads caused by the wheels of the vehicles.

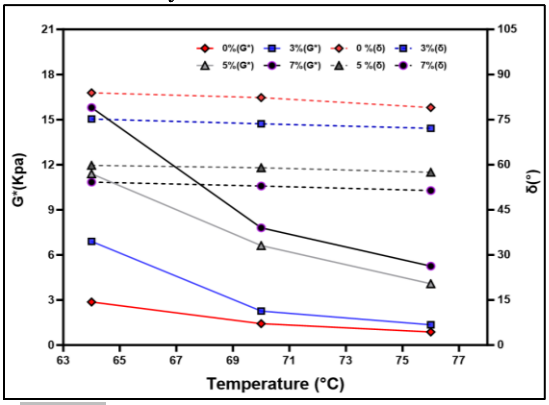

Fig. 17 The Relationship between Complex Shear Modulus (G*) and Phase Angle (δ) at Different Temperatures of Various SBS Modifier Contents.

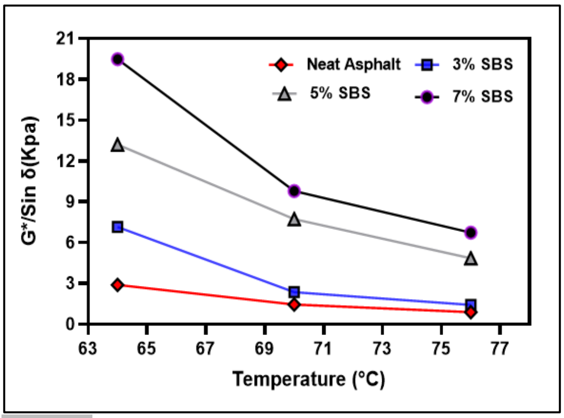

Fig. 18 The Relationship between the Rutting Factor (G*/Sin δ) and Different Temperatures.

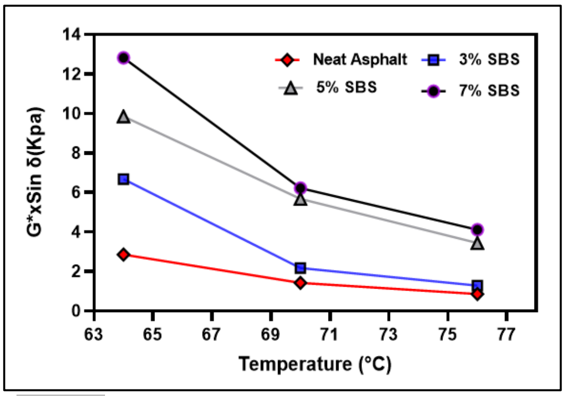

Fig. 19 The Correlation between the Fatigue Factor (G*× Sin δ) and the Varying Temperatures.

3.7.Storage Stability Test

Asphalt binder stability during storage was evaluated according to the following steps (as seen in Fig. 20). The sample was put in an aluminum foil tube (32 mm in diameter by 160 mm in height). The tube containing the modified asphalt was placed in the oven for 48 hours at a temperature of 160 °C, then extracted from the oven, left to cool, and then placed vertically in a freezer for four hours to cool down before being cut horizontally into three equal pieces. The tube's top and bottom halves were tested to see how much difference there was in their respective softening points. When the change was less than 4 °C, the sample was considered stable throughout storage [51, 52]. It is considered one of the general tests for bitumen and measures the isolation extent of the bitumen additive during the use of the road at the layer's top and bottom. This test was conducted according to the requirements outlined in ASTM D7173 [53]. Highway construction might be slowed by inclement weather, such as rain, making storage stability among the most important characteristics of modified asphalt binders. The effect of the storage period on uniformity at higher temperatures was investigated by keeping the binder in a vertical posture for two days in an aluminum tube heated to 165 °C. In the presence of a difference between the two parts, it is most likely that the softness in the upper part is greater than the lower one due to a lack of good mixing and the rise of the SBS polymer to the top due to its lightweight.

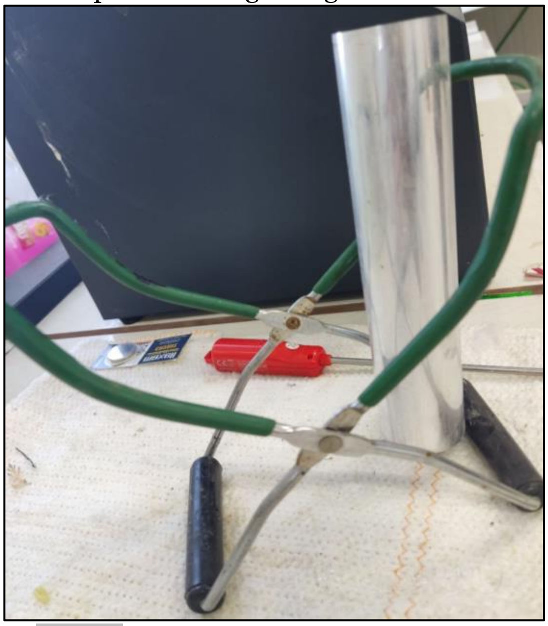

Fig.20 Aluminum Foil Tube for Storage Stability Test.

Fig.21 shows a clear difference after adding 7% of the SBS polymer. An explanation for this is that the SBS increase in the asphalt by more than 5% led to the completion of the hydrogen bonds formation in the regular asphalt and caused the agglomeration of the asphalt and the isolation of the SBS granules and their rise to the top due to their lightweight. Therefore, the optimal ratio to add SBS to the regular asphalt was 5%.

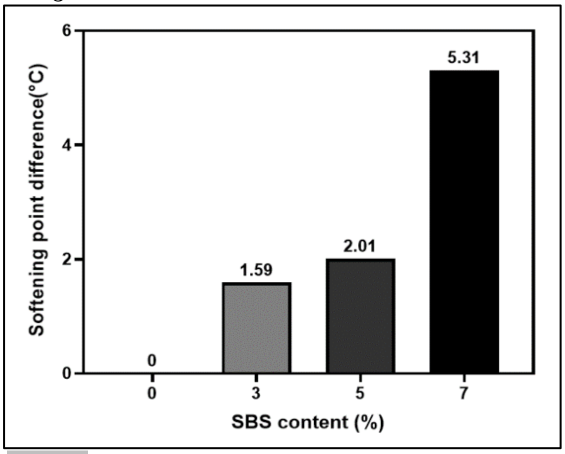

Fig.21 The Variation in the Softening Point of the SBS Content Between the upper and Bottom Portion.

3.8.FTIR Test

The FTIR analysis was conducted on two samples of asphalt, one unmodified and the other modified with SBS. For the neat bitumen binders, FTIR spectroscopy revealed peaks at wavenumbers of 2917.85 cm^{-1}, 2852.76 cm^{-1}, 1451.42 cm^{-1}, and 1024.41 cm^{-1}, as displayed in Fig. 22.

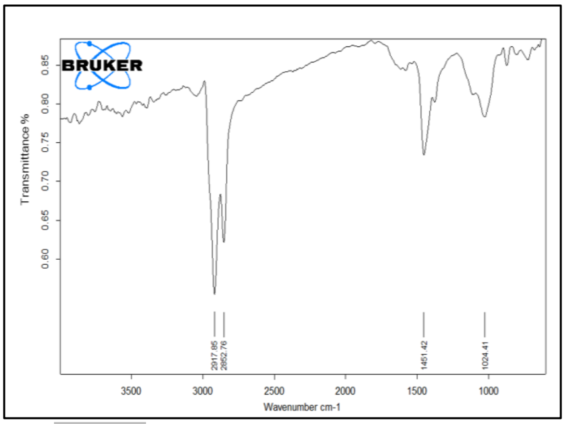

Fig. 22 FTIR Results of Neat Asphalt.

The analysis of the sample's spectral data revealed the presence of the following components in the neat binder: methylene (-CH_2) stretching, special methyl (-CH_3) stretching, aromatic (C=C) ring skeleton vibration, and aliphatic fluoro compounds (C-F) stretching vibration, as shown in Table 6. This explanation is based on the elemental wavenumbers in the test findings supported by the correlation table used to interpret the FTIR readings [54]. Table 6 displays a summary of the FTIR test values on neat asphalt.

Table 6 Summary of the FTIR Outcomes of Neat Asphalt.

Vibration Types	Functional Group	Frequency Range (cm^{-1})	Their Frequency (cm^{-1})
Saturated Aliphatic(alkene)	Methylene (C-H) Stretch	2935-2915	2917.85
Saturated Aliphatic(alkene)	Special methyl frequencies, Methylamino (C-H) Stretch	2820-2780	2852.76
Aromatic ring	Aromatic ring (C=C) Stretch	1510-1450	1451.42
Aliphatic organohalogen compound	Aliphatic fluoro compounds (C-F) Stretch	1150-1000	10241.41

Compared with the findings obtained with neat asphalt, the tests conducted on PMB indicated the presence of five new function groups, which were seen in the form of peaks in the FTIR readings, which might indicate the appearance of new chemical components. As a result, a significant chemical reaction likely resulted in the production of PMB. The FTIR spectroscopy for the modified binder reveals peaks at wavenumbers of 3736.25 cm^{-1}, 3296.37 cm^{-1}, 2358.45 cm^{-1}, 1578.56 cm^{-1}, and 872.25 cm^{-1}. These wavenumbers represent the following elements that were included: (O-H) stretching and (C=O) stretching of CO_2, which represents a by-product composite resulting from the active reaction of the polymeric' (OH) with oxygen when heated and exposed to air during the test in the laboratory, as agreed with previous research [34, 42, 55]. The contraction of the peak at 1578.56 cm $^{-1}$ and 872.25 cm $^{-1}$ represents stretching of the (C=C) and (C-H), respectively. Firstly, increasing the polar covalent link O-H and reducing the nonpolar covalent bond(C-H) increases the viscosity of asphalt binder. Second, SBS contains polybutadiene segments and polystyrene chains, giving it more toughness and strength than pure asphalt. Table 7 and Fig.23 show the results of the FTIR test on modified asphalt with SBS.

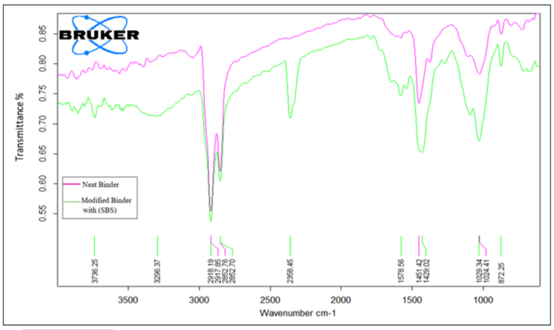

Fig. 23 FTIR Results of Neat and Modified Asphalt Binder.

Table 7 Summary of the FTIR Result of Modified Asphalt Binder.

Vibration Types	Functional Group	Frequency Range (cm^{-1})	Their Frequency (cm-1)
Alcohol	Primary Alcohol (O-H) Stretch	4000-3000	3736.25
Alcohol and Hydroxy Compound	Normal " Polymeric" (OH) Stretch	3400-3200	3296.37
Aromatic Ring	Carbon (O=C=O) Stretch	2000-2400	2358.45
The Aromatic Ring (aryl)	The Aromatic Ring (C=C) Stretch	1651-1580	1578.56
Aromatic Ring	Aromatic (C-H) out-of-Plane Blend	670-900	872.25

4.CONCLUSIONS

The purpose of this study is to ascertain the impact of the addition of the SBS modifier on the neat asphalt binders' performance. The following are the primary conclusions of the present research:

- The SBS polymer modified the physical and chemical properties of the asphalt binder. The increase in the percentage of SBS modification produced a rise in the softening point and an increase in viscosity, toughness, and tenacity at low temperatures while simultaneously causing a decrease in penetration.
- Using SBS polymers reduced the bitumen's temperature susceptibilities, which increased asphalt's stiffness. This study suggests that SBS-modified binders are useful in Iraq, especially in places where summer temperatures are high, and can enhance the HMA adhesive and cohesive characteristics.
- The DSR test found that the neat asphalt from the Dhi Qar refinery failed at a temperature of 76 °C, so it is exposed to cracks; therefore, when used on roads in Iraq, it causes rutting and fatigue cracking. However, with the use of the polymerized bitumen, a significant improvement in the properties of PMB, which could withstand high temperatures up to 88 °C, was noticed. Hence, the SBS modifier resulted in a higher rutting coefficient and fatigue cracking than neat asphalt.
- According to the results of the laboratory tests, 5% of the SBS modifier was the optimum percentage in terms of the physical characteristics of neat asphalt.
- The compatibility test results indicated that the stability of the polymerized bitumen was achieved at a 5% addition of SBS. The higher percentage of SBS led to separating SBS from the bitumen due to its lightweight nature. Consequently, that will lead to a similar separation between the top and bottom of the surface layer.
- Peaks at wavenumbers of 3736.25 cm^{-1}, 3296.37 cm^{-1}, 2358.45 cm^{-1}, 1578.56 cm^{-1}, and 872.25 cm^{-1} were seen in SBS-modified asphalt binders with better performance as opposed to non-peaks in the original asphalt binders, which implies that FTIR analysis can determine whether or not an asphalt binder has undergone a SBS modification.
- As determined by FTIR analysis, the peaks of binders modified with SBS polymers appeared at the 3296.37 cm^{-1} and 3736.25 cm^{-1} wavenumbers. There was a noticeable variation in peak values between the neat asphalt binder and the modified binders with SBS polymers, which indicates that increasing the polar covalent link O-H and decreasing the nonpolar covalent bond C-H increased the asphalt toughness.
- Due to the superior laboratory performance and durability of SBS-modified asphalt, it was used extensively in road engineering.

RECOMMENDATIONS

It is preferable to conduct Superpave tests after aging for modified bitumen for all concentrations (3, 5, and 7%) of SBS, such as mass change after the Rolling Thin Film Oven (RTFO) test, as well as the DSR tester, Bending Beam Rheometer (BBR) test, and the remaining tests of Superpave.

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