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EVALUATION OF THE PHYSICAL AND RHEOLOGY PROPERTIES OF RUBBERIZED ASPHALT CEMENT

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Asphalt cement is a viscoelastic substance that operates like an elastic solid at low service temperatures or under rapid loading. Whenever loaded slowly or at high temperatures, it behaves like a viscous liquid. This classic duality necessitates enhancing the efficiency of an asphalt binder to decrease stress cracking at cold temperatures (fatigue) and plastic deformation at hot temperatures (rutting). The use of polymer-modified asphalt binder is one solution for satisfying today's pavement performance standards. The purpose of this study was to determine the impact of asphalt cement modifiers on the physical and rheological properties of asphalt cement. This study used asphalt cement with a penetration grade of 40-50, modified with styrene-butadiene rubber (SBR) at four different levels of modification, specifically 0%, 2%, 4%, and 6% by weight of asphalt cement. Depending on Rotational viscosity and dynamic shear rheometer, and the traditional test. The mixes modified with SBR polymer showed enhanced physical and rheology characteristics, with decreased penetration and ductility and increased viscosity and softening point, as well as a lower rutting factor, indicating an increase in rutting resistance, according to the experimental data. The performance grade for original asphalt cement was 64-16, and for SBR at 2% additive, the original PG was improved to PG70-16. Adding 4% additive to asphalt cement improved the performance grade to PG76-16, and using 6% increased the performance grade to PG82-16.

Keywords: rheology, physical, SBR, dynamic shear rheometer, viscosity

1 INTRODUCTION

Asphalt has traditionally used as a road pavement binder. Unfortunately, HMA suffers from high-temperature rutting and low-temperature cracking, which is due to its high-temperature susceptibility [1]. As a result, asphalt must be modified. The physical properties and durability of polymer modified asphalt binders (PMABs) are superior to those of unmodified asphalt binders. Asphalt modifiers can improve the physical qualities as well as the mechanical performance at medium and high temperatures [2]. Polymers have been added to asphalt in European countries since 1960. Polymer-modified asphalt mainly composed more than 8% of the asphalt used on French roads in 1993[3]. The necessary modification of the asphalt binder is required for improving safety, dependable, and environmentally sustainable flexible paving materials [4]. With the increasing growth in traffic volume and frequency, the original asphalt can hardly achieve both high- and low-temperature performance criteria at the same time [5].

Fortunately, research has discovered that high-performance asphalt binders can be made by blending polymers mechanically or through a chemical reaction technique. Various polymers, such as styrene-butadiene-styrene (SBS), styrene-butadiene-rubber (SBR), and polyethylene (PE), have been utilized to modify the original asphalt to enhance the capacity of road pavement [6]. Furthermore, research shows that the content and type of polymers in the asphalt have a substantial impact on the asphalt pavement's durability [7].

In the field of enhancing pavement mechanical performance, it is essential to consider the mechanisms of complicated behaviors of asphalt concrete mixtures. The technical features of asphalt concrete mixtures are influenced by two important factors: aggregate gradation and asphalt cement; fundamentally, the asphalt binder is the component that influences the mix viscous behavior and is made up of asphalt cement and modifier. Many studies suggest that a certain polymer is a viable modifier for improving the asphalt binder qualities and, as a result, the viscoelastic properties of the mixture. The study of bitumen rheology is a significant aspect of determining the dynamic mechanical behavior of binders [8].

The polymer features (Plastomers, Elastomers) and content, as well as the bitumen nature, influence the qualities of rubberized asphalt cement. Elastomers with high elastic response, such as styrene-butadiene rubber (SBR) and styrene butadiene styrene (SBS), resist permanent deformation by stretching and recovering their original shape. They also have increased tensile strength with elongation and the ability to return to their original condition after an applied load is removed, as a binder modifier, SBR is commonly utilized.

Some of the benefits of SBR modified asphalt in enhancing the qualities of asphalt concrete pavement are described in an Engineering Brief from 1987 available on the US Federal Aviation Administration website [9]. Low-temperature ductility is improved, viscosity is increased, elastic recovery is improved, and the pavement's adhesive and cohesive qualities are enhanced. As a result, the need for the usage of SBR to improve the performance of local asphalt concrete has become noticeable. It's a general-purpose rubber composed of around 75% styrene and 25% butadiene linked together in a co-polymer. Styrene improves the bonding and blending capabilities, as well as the abrasion resistance and strength of SBR. The use of SBR as a modifier is projected to result in a large increase in viscosity, as well as improvements in elasticity, adhesion, and cohesive qualities of the pavement. The ductility of the asphalt pavement will be increased as a result of the good cohesion of SBR polymers, allowing for additional flexibility [5]. When the SBR content was increased to 3–5%, the performance was enhanced overall, and in one case, storage stability was improved by adding other materials, implying that there may be a possible benefit when mixing other modifiers [10].

The primary goal of this research is to assess the physical and rheological properties of asphalt concrete mixtures containing SBR polymer using the following tests: penetration test, ductility test, and softening point test to assess the physical properties of SBR modified asphalt cement. The rheology parameters and performance grade of SBR modified asphalt cement were investigated using rotational viscosity and a dynamic shear rheometer.

2 MATERIAL

A bitumen binder with a penetration grade of 40-50 was employed in this project. It originated from the Dora refinery, which is located southwest of Baghdad. Table 1 shows the physical properties of asphalt cement.

In this research, styrene-butadiene rubber (SBR) was employed as an addition to the asphalt cement. Preparation of rubberized bitumen binder was employed in the SBR modifier that passed the 30-mesh sieve. The rubberized bitumen binder was made in the lab at a temperature of 180°C and a time of 60 minutes of blending. By initially heating the bitumen to 180°C, three different concentrations of SBR were created. Table 2 shows the physicochemical characteristics of SBR.

Table 1. The Physical Properties of Asphalt Cement

Test	Test result	ASTM Designation
Penetration (25°C , 100g, 5 s), (0.1mm)	47	D-5
Ductility (25 °C, 5 cm/min), cm	100≥	D-113
Softening point (ring and ball method), °C	57	D-36
Flashpoint, °C	270	D-92
Specific gravity (25/25°C)	1.048	D-70

Table 2. Physiochemical Properties of SBR

Property Test	Results
The Polymer structure	Elastomers
PH	9-10.5
Specific gravity	1.01
The Compressive strength	40 MPa
The Tensile strength	6.5 MPa
The Flexural strength	13 MPa
A Solid content	75% Butadiene, 25% Styrene

3 EXPERIMENTAL TEST

3.1 Test for investigating Physical properties

Asphalt binder (asphalt cement and SBR mixes) were made and tested utilizing traditional binder tests such as penetration (ASTM D5), ductility (ASTM D 113), softening point (ASTM D36), and thin-film oven test (ASTM D 1754) to examine physical properties of asphalt binder after aging.

3.2 Test to evaluate rheology properties

3.2.1 Rotational viscosity test

This test was conducted on unmodified asphalt cement as well as modified asphalt cement containing 2%, 4 %, and % SBR by asphalt weight. The viscosity was determined at two different temperatures: 135°C and 165°C. The difference in viscosity between the original and changed asphalt was measured using a rotational viscometer (RV).

3.2.2 The Dynamic Shear Rheometer test

The most popular technique for determining the essential rheological characteristics of binders was DSR oscillatory dynamic mechanical analysis according to AASHTO T 315 employing parallel plate test geometry. The above test technique is used to estimate the asphalt binder's dynamic shear modulus G* and phase shift angle when tested under dynamic (oscillatory) shear. A DSR temperature sweep test was done in a controlled strain at a constant frequency rate of 10 rad/s. Bohlin DSR as shown in Fig. 1 used to determine original and RTFOT (Rolling Thin Film Oven Test) aging, to assess the samples. To represent short-term aging caused by oxidation, which occurs often during binder mixing, RTFOT aging was carried out in accordance with ASTM D2872 standard specifications. The aging process lasts 85 minutes, with the carriage revolving at 15 rpm and maintaining a constant temperature of 163 ^{o}C.

For physical properties testing, a Pressure Aging Vessel (PAV) was used to simulate long-term field oxidative aging of asphalt binders. Heat and pressure are applied to the asphalt binder to imitate in-service aging during a 7 to 10-year duration. The PAV procedure is usually carried out for 20 hours at 90, 100, or 110 degrees Celsius.

(a) **(b)**

Fig. 1. (a) Dynamic Shear Rheometer Instrument, (b) Specimen in The Silicon Mold

4 RESULTS AND DISCUSSION

4.1 The Physical Properties of SBR-modified asphalt cement

The influence of additive SBR modification on the conventional properties of asphalt cement can explain in Fig. 2 the penetration values decreased with the additives percent increasing from 2% to 6% by the weight of asphalt. The reduction in penetration ranged from (47) to (34) for an increment in the SBR content from (0%) to (6%).

After the rolling thin film oven test, the penetration of asphalt cement decreased because the asphalt cement suffers from oxidation and is less volatile, causing significant changes inside the physical and chemical properties of the asphalt [11]. The percentage of reduction in penetration value after aging were (7%,7.5%,8, and 15%) for (0%,2%, 4%, and 6%) respectively.

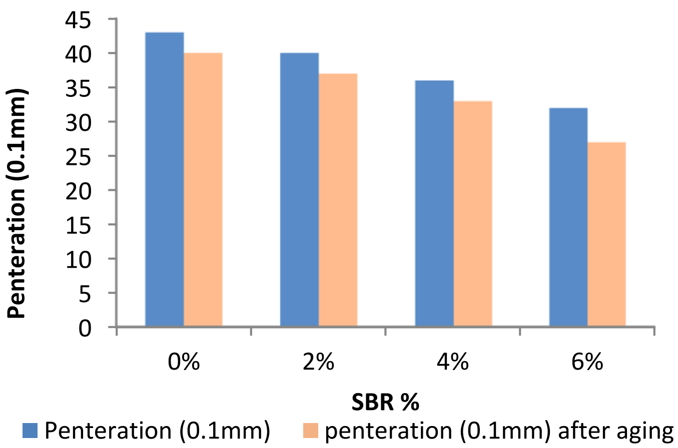

Fig. 2. Penetration Value of SBR Modified Asphalt Cement

The modified and unmodified asphalt binders were subjected to a ductility test at 25°C to determine their tensile properties. The results are shown in Figure (3), and they show that as the modifier concentration increases, the ductility of the original asphalt tends to decrease. original asphalt had a ductility value of 125 cm, which was reduced to 13 cm with the addition of 2% SBR, 29 cm with the addition of 4% SBR, and 41 cm with the addition of 6% SBR. The percentage reduction in ductility of the original asphalt value was 10%, 23%, and 33%, respectively. These significant reductions in ductility show that the addition of an SBR modifier at a concentration of 2–6% by weight of each asphalt binder's modifier resulted in a significant loss of the original asphalt's flexibility. Due to aging processes and loss of volatile after high-temperature exposure, the ductility value of asphalt binder reduced after thin film oven testing.

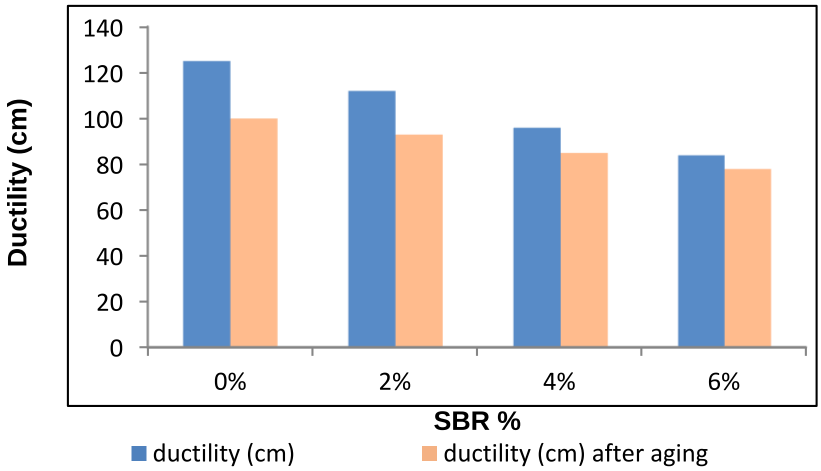

Fig. 3. Ductility Value of SBR Modified Asphalt Cement

As illustrated in Fig. 4, softening point increased as the percentage of additives increased from 2% to 6% by weight of asphalt cement. The original asphalt's softening point temperature was 57°C. In the case of SBR (2,4, and 6%), the percentage increase in softening point of the original asphalt binder value was 3.5 %, 10.5 %, and 17.5 %, respectively.

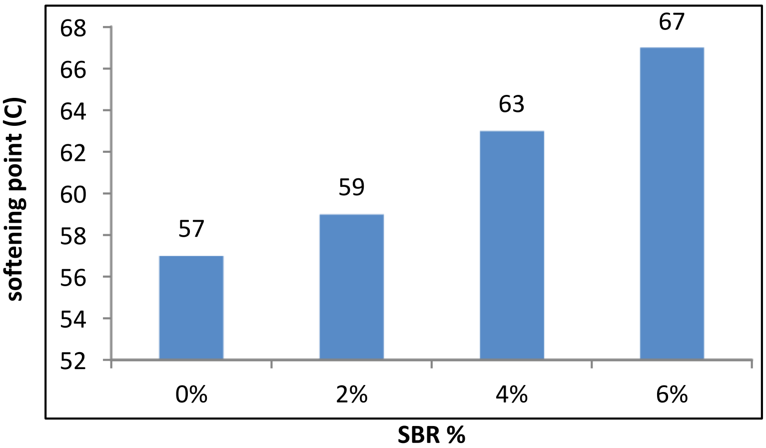

Fig. 4. Softening Point Value of SBR Modified Asphalt Cement

4.2 Temperature susceptibility

Using the results of penetration and softening point tests, the temperature susceptibility of modified bitumen samples was assessed in terms of penetration index (PI). The change in the consistency parameter as a function of temperature is known as temperature susceptibility. In the Shell Bitumen Handbook [12], a traditional way to PI computation is shown with the following equation.1

$$PI = \frac{1952-500\log(pen25)-20*Tsp}{50*\log(pen25)-Tsp-120} \qquad (1)$$

Where: -

Pen 25 = the penetration value at 25°C,

Tsp= temperature of softening point, °C

The use of SBR in asphalt cement reduces the bitumen's temperature susceptibility, as evidenced by an increased penetration index (PI) as illustrated in Fig. 5, dependent on eq. 1

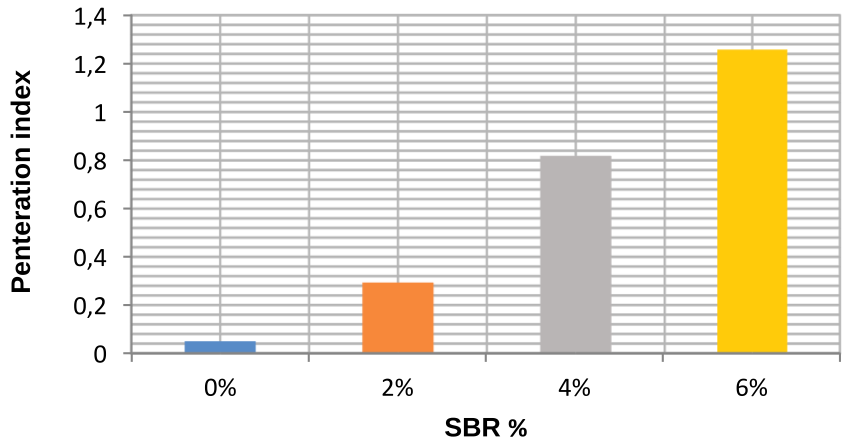

Fig. 5. Penetration Index Values

4.3 Rheology Properties of SBR-modified asphalt cement

Rotational viscosity and dynamic shear rheometer tests were conducted to investigate the rheology properties of SBR-modified asphalt cement.

4.3.1 Rotational Viscosity Result

The use of SBR enhances the viscosity of the binders; previous research has found that the characteristics of SBR induce a significant increase in the viscosity of the modified binders. Binders with a high viscosity have been found to have a negative influence on workability throughout the preparation process [13].

The effect of SBR on asphalt binder viscosity The finding of rotational viscosity, as shown in Table 3, supports this conclusion.

• At 135 ℃, the rotational viscosity of SBR –modified asphalt cement (2 %, 4%, and 6%) expanded to 140 %, 300 %, and 424 %, respectively, while at 165 ℃, it increased to 39 %, 104 %, and 213 %, respectively.

•. It also shows that as the amount of SBR added to the asphalt rises, the viscosity improves. As a result, the workability of the asphalt binder becomes more difficult, and higher temperatures are required for mixing and compaction.

• The analysis indicates that as the temperature rises, the viscosity of the asphalt binder tends to decrease.

Table 3. Rotational Viscosity Result

Testing temp.	original	2% SBR	4% SBR	6% SBR
135℃	0.482	1.16	1.932	2.527
165℃	0.135	0.188	0.275	0.422

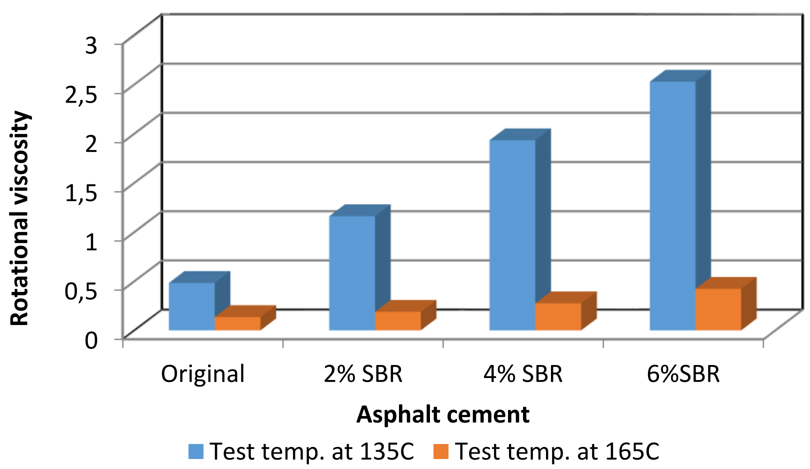

Fig. 6. Rotational Viscosity of SBR Modified Asphalt Mixture

4.3.2 Result of Dynamic shear rheometer test

The DSR test is used to determine rheological qualities that are directly connected to field performance. Both the complex shear modulus (G*), and phase angle (δ) can be calculated using the DSR test. G* denotes a material's ability to resist any type of deformation under the applied loads. It can be used as a predictor of the stiffness of asphalt binder film at specified loading rates and temperatures. The complex shear modulus is defined as ratio of a value of complex shear stress to a value of complex shear strain. G* is comprised of the elastic part (the storage modulus ($G^{/}$) and the viscous part (the loss modulus ($G^{//}$). The phase angle (δ) is a measure obtained from DSR testing results that is used as a predictor of material viscoelastic equilibrium. It is described as the phase angle that occurs during testing between the application of complex shear stress and the reaction to complex shear strain. This indicates that the (δ) value will change from 0 to 90 degrees, and the nature of asphalt cement will change from elastic to viscous. This test consists of three aging periods.

1. **The original aging**

According to standard specification AASHTO T 315, the results of rutting parameters for original aging (G*/sinδ) where the specification limit 1 kPa, Min, from Table (4) it can be noticed the rutting parameter (G*/sinδ) decreased by increased the test temperature. The rutting parameter increased by increasing the percentage of additive. The SBR modified asphalt binder has higher rutting parameter (G*/sinδ) than that of original asphalt binder, Figure (7) explain the effect of SBR of the rutting parameter of original asphalt cement at 64 °C.

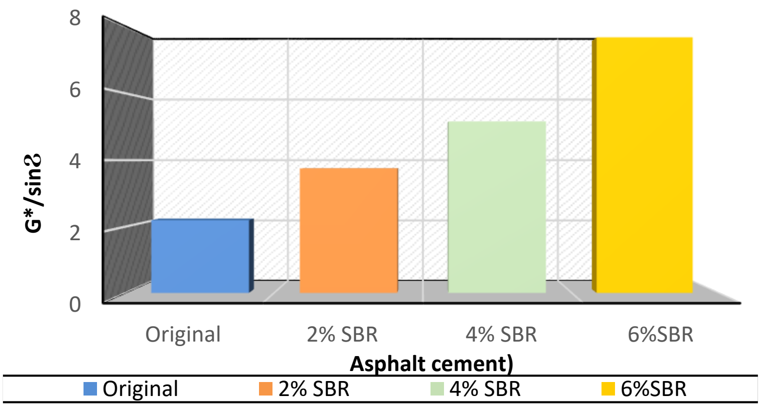

Fig. 7. Effect of SBR on Original Asphalt Rutting Parameter at The Original Aging

2. **Rolling Thin Film Oven test (RTFOT)**

The rutting behavior of modified and unmodified asphalt cement was determined by DSR according to AASHTO T240-13 (G*/sinδ) kPa at frequency 10 rad/sec. The specified limit is 2.2 KPa. The increase in the parameter of rutting after short-term aging by RTFO test, as shown in Table (4), is due to the volatilization of gasses components from the asphalt cement, as well as the loss of chemical components responsible for asphalt flexibility and the transformation of the asphalt into hard materials. Due to an increase in viscosity while simultaneously lowering the phase angle. The DSR test result of a higher G*/sinδ value indicates that the binders are more effective resisting rutting at high pavement temperatures. At 64°C, the G*/sinδ values of binders were investigated in their original and RTFO forms. The results of the tests on the original binders are shown in Figure (8). The G*/sinδ values were increased when an SBR modifier was included. As a result, it is clear that the use of an SBR modifier improves the binders' rutting resistance.

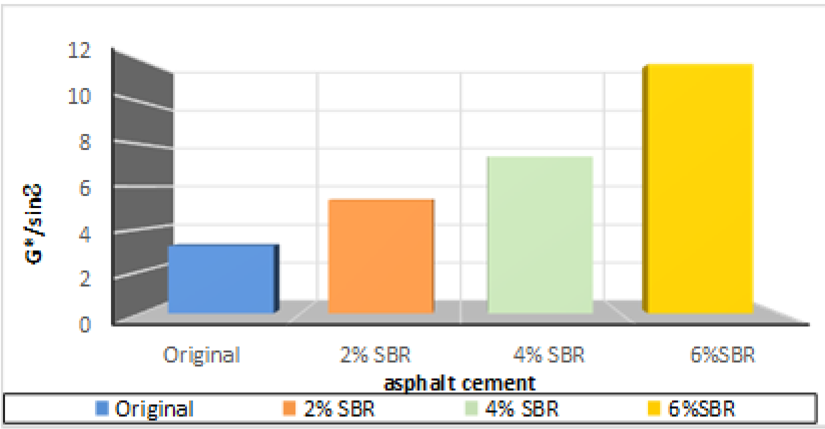

Fig. 8. Effect of SBR on Original Asphalt Rutting Parameter at the RTFOT aging

3. Pressure aging vessel PAV test

The fatigue parameter (G*.sinδ) for the original asphalt was 4540 kPa at 28°C during long-term aging by PAV test, where the specified limit was 5000 kPa according to AASHTO R28-12 designation (2016). Fatigue parameters (G*. sinδ) of 2 %, 4 %, and 6 % SBR modified binders were established and passed the Superpave criteria at 31 C°. Low-temperature cracks were not influenced in any of the results, and SBR reduced G*.sin δ by roughly 1.7 %, 2 %, and 5% when utilizing 2%, 4 %, and 6% SBR, respectively.

Table 4. SHRP Parameters Obtained from Super Pave Test (Original and RTFO aging test)

Asphalt cement	0% SBR	2% SBR	4% SBR	6% SBR	specification limit
Original aging test					
G*/sinδ, @ 10rad/sec, (KPa)	@64°C 2.19 @70°C 0.82 @76°C …… @82°C ……. @88°C …….	@64°C 3.75 @70°C 1.27 @76°C 0.587 @82°C …… @88°C …….	@64°C 5.16 @70°C 3.86 @76°C 1.18 @82°C 0.52 @88°C …..	@64°C 7.68 @70°C 5.74 @76°C 2.12 @82°C 1.03 @88°C 0.478	≥1 kPa
RTFO aging test					
G*/sinδ, @ 10rad/sec, (KPa)	@64°C 3.2 @70°C 1.92 @76°C ….. @82°C …… @88°C ……	@64°C 5.37 @70°C 2.13 @76°C 1.85 @82°C …… @88°C ……	@64°C 7.42 @70°C 4.66 @76°C 2.55 @82°C 1.69 @88°C ……	@64°C 11.8 @70°C 8.21 @76°C 6.43 @82°C 2.87 @88°C 1.78	≥2.2 kPa
PAVaging test					
G*.sinδ, @ 10rad/sec, (KPa)	@28°C 4580	@31°C 4500	@ 31°C 4453	@ 31°C 4320	Max 5000 kPa
Stiffness MPa	@-16 185	@-16 215	@-16 227	@-16 242	300MPa
M- Value	@-16 0.38	@-16 0.375	@-16 0.354	@-16 0.339	Min 0.3

Fig. 9 illustrates the stiffness of the original and all percentages of SBR-modified asphalt binder utilized in this research at low temperatures. As seen, low temperature is unaffected; however, when stiffness is increased at low temperatures, low-temperature sensitivity rises. The stiffness of asphalt binder increases by approximately 16, 23, 31% for 2, 4, and 6% SBR modified asphalt binder at low temperatures, making SBR modified asphalt cement more effective.

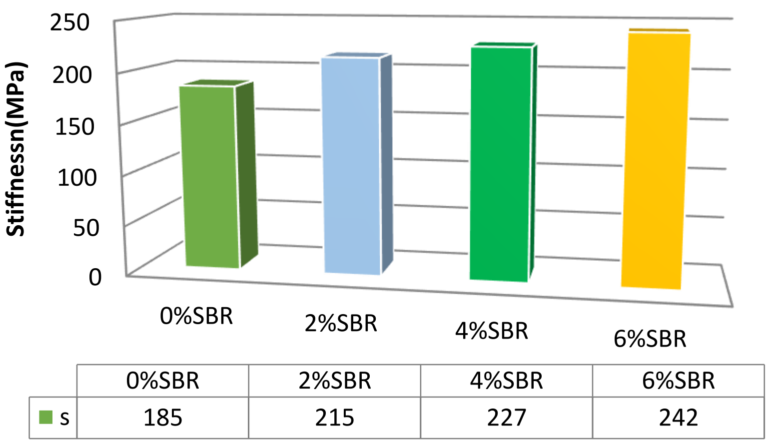

Fig. 9 The Stiffness Binder

The performance of original asphalt can be categorized as PG 64-16, according to AASHTO (2015) M 320-10. While utilizing a 2% SBR modified binder, the performance grade increased (PG 70-16), when increasing the modifier to 4%, the performance grade increased (PG 76-16), and when using a 6% SBR modified asphalt binder, the performance grade improved (PG 82-16) as explained in Fig. 10.

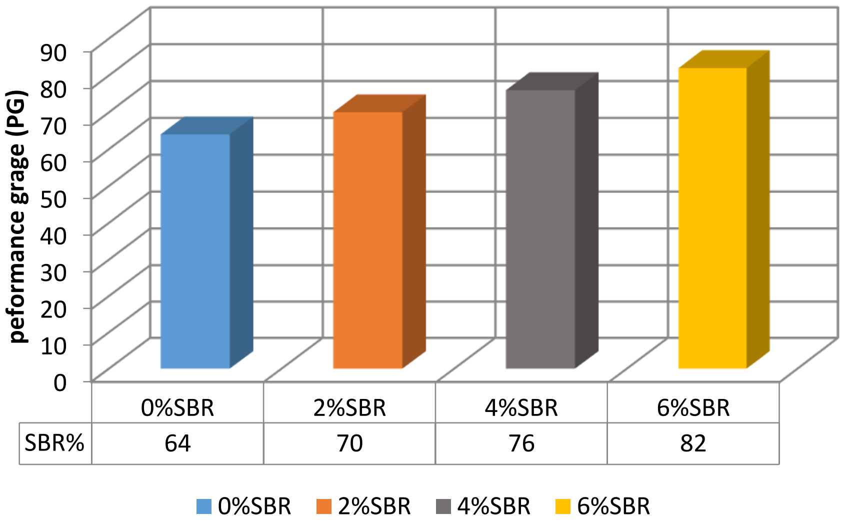

Fig. 10. The Performance Grade of Modified Asphalt Cement

5 CONCLUSION

According to the results of the tests and the methods used in this study, adding SBR to asphalt cement has a noticeable effect on the rheological and physical properties of the asphalt cement. The additive was added to the asphalt cement at a rate of 2%, 4%, and 6% by weight of asphalt, resulting in a modified asphalt cement binder that can be employed in highway paving to improve performance and service life. As a result, the following conclusion can be explained:

- As a result of the SBR modification, the consistency of the binder has been enhanced (reduce penetration and increase in softening point). The softening point tends to rise with the addition of SBR, showing improved deformation resistance.
- Penetration index data indicate that adding the SBR modifier decreased the original asphalt's temperature susceptibility, as shown by an increasing penetration index.
- As the concentration of SBR modifier was increased, ductility reduced, indicating that asphalt shear resistance improved.
- After thin film oven testing, penetration and ductility decreased, indicating that the asphalt binder was affected by (heat and air) aging, making the binder hard and reducing volume fraction.
- SBR modified asphalt cement has a higher rotational viscosity. As a result, the asphalt mixture's viscosity rises, and permanent deformation decreases. The viscosity increased as the concentration ratio increased as 140 %, 300 %, and 424 %, at 135 ℃, while at 165℃ , it increased to 39 %, 104 %, and 213 %, for 2%,4%, and 6% SBR ratio respectively.
- Adding SBR to bitumen improves the rutting parameter, resulting in increased rutting resistance of the rubberized pavement mix.
- The stiffness of the modified asphalt binder increased, resulting in greater sensitivity to low temperatures in the low-temperature test. For 2, 4, and 6% SBR modified asphalt binder, the stiffness of the asphalt binder rises by around 16, 23, and 31%, respectively.
- When employing 2%, 4 %, and 6 % SBR modified asphalt cement, the fatigue parameter G*.sinδ decreases by around 3 %, 2 %, and 5 %, respectively.
- The PG64-16 performance grade is the same as the original asphalt penetration grade (40-50). The modified asphalt binder had a good impact on the aging process when compared to the original asphalt; as a result, the modified asphalt's fatigue cracking and rutting resistance will be improved.
- The performance grade of SBR at 2% additive improved the original PG to PG70-16, 4% additive to asphalt cement improved the performance grade to PG-76-16, and 6% additive to asphalt cement improved the performance grade to PG82-16.

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