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THE FEASIBILITY OF USING STYRENE-BUTADIENE-STYRENE (SBS) AS MODIFIER IN IRAQI BITUMINOUS BINDER

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Abstract

The increase in the number of trucks and other heavy vehicles in Iraqi highways lead to cracking and deteriorations in the flexible highway. The use of polymer-modified asphalt may solve this problem to match the required performance standards. This study investigates the effects of styrene-butadiene-styrene (SBS) polymer on the performance behaviour of Iraqi bitumen binder. The characteristics of bitumen binder were analysed to observe the compatibility of bitumen with SBS polymer. The bitumen binder was mixed with three different contents of SBS (4%, 4.5%, and 5%) by weight of asphalt cement. Viscosity tests were conducted on the SBS polymer-modified asphalt at 135 °C and 165 °C in addition to conventional binder tests. The preparation of the asphalt concrete mixes was done at a fixed optimum asphalt content of 4.7% and evaluated for moisture resistance and Marshall Stability. From the test result, the modification of the binders with SBS increased the binder consistency by reducing the penetration and increasing the softening point. The SBS modification also reduced the susceptibility of bitumen to temperature as evidenced by the improved penetration index. Moreover, the relationship between mixing and compaction temperatures with SBS modification is a positive relationship. The asphalt mixes modified with SBS have shown a developed of Marshall Stability and high durability against environmental effects.

Keywords: Styrene-butadiene-styrene, Modified binder, Viscosity, Rheological properties, Temperature sensitivity.

1. Introduction

Some asphaltic roads in Iraq suffer from many distresses, such as moisture damage which occurs within the asphalt pavement and causes stripping and potholes. The susceptibility of pavements to moisture also contributes to other types of pavement damages, such as fatigue and rutting. The use of polymer-modified asphalt may solve this problem to match the required performance standards.

The use of PMB in pavement construction is an important step in increasing the durability and life of asphalt roads [1]. Therefore, various studies have reported the use of polymer modified bitumen (PMB) to improve the performance of pavements. However, the characteristics of PMB rely on the characteristics of the polymer used to make them, as well as on the nature of the bitumen used. There are two basic types of polymers used for bitumen modification for road use, these are plastomers and elastomers. Polymers regarded as plastomers, such as Ethyl-vinyl-acetate (EVA), Polyvinyl chloride (PVC), and Ethylene propylene (EPDM), are mainly used for the modification of bitumen as they form a tough and stable 3-D network that confers resistance against deformation. On the other hand, the elastomers, such as styrene butadiene styrene (SBS) and styrene butadiene rubber (SBR) are characterized by a high elastic response; hence, they are resistant to permanent deformation as they can stretch and recover their initial shape. They also portray high tensile strengths upon stretching and can recover their initial condition after exposure to stress [2].

SBS-modified asphalt is produced from asphalt mixed with a certain percentage of SBS modifier through shearing, stirring and other mixing methods that ensure the even dispersal of SBS in the asphalt [3].

The effect of using SBS with hydrated lime on the resistance of asphalt mixtures to moisture damage has been studied by Kok and Yilamz [4]. The results showed SBS to confer good resistance to moisture damage by increasing the resistance of the modified asphalt to moisture damage.

The rheological properties of SBS copolymer modified bitumen (PMB) was assessed by Słowik [5] using about 0-9% of SBS copolymer as a modifier. The results showed the SBS content to have a significant influence on the reduction of the susceptibility of the asphalt binders to temperature.

In Iraq, Obaid [6] studies the effect of SBS content on moisture damage resistance and the SBS content was (0.5, 1.0, 1.5, 2.0, 2.5, 3.0.3.5, 4.0) percent by the weight of asphalt. The author found that modified mixture with adding 3% of SBS exhibited greater resistance to moisture damage than unmodified mixtures. Moreover, Naser [7] investigates the effect of SBS polymer on the mechanical properties of hot mixtures asphalt which is used in the rehabilitation of Baghdad province and Al-Basra province highway by paving the surface course of highway for areas suffers from problems such as rutting and cracks. The author recommended using SBS modified mixture for paving of new flexible pavement layers and in the rehabilitation of the surface course of the old flexible pavement.

The aim of this study is to evaluate the rheological properties of modified asphalt binder with SBS, which is mainly applied in hot mix asphalt (HMA) for the surface layer of road pavements. Therefore, the virgin bitumen was mixed with three different contents of SBS (4%, 4.5%, and 5%). The preparation of the asphalt concrete mixes was done at a fixed optimum asphalt content of 4.7% and evaluated for mechanical properties such as Marshall Stability and index of retained strength test.

2. Experimental

2.1. Raw materials

Table 1 presents the type and source of the materials utilized in this work. The grade of the aggregates used in this study followed the local specification requirements [8] for the wearing course. The nominal maximum size of 12.5 mm (1/2" in) was ensured (refer to Table 2 and Fig. 1). The aggregates were subjected to routine tests to verify their physical properties and the observations were presented in Table 3. Figure 2 is a photograph of the SBS modifier used in this study. The percentage of the SBS modifier used in this work was 4%, 4.5%, and 5% by weight of the asphalt binder.

Table 1. Source of raw materials.

Materials	Type	Source
Asphalt Binder	AC(40-50)	AL-Daurah Refinery
Aggregate	Fully Crushed	Al-Nibaie Quarry
Filler	Ordinary Portland Cement	Local Market
Modifier	Styrene- Butadiene-Styrene Polymer	State Company for Mining Industry

Table 2. Aggregate gradation for wearing course.

English Sieves	Standard Sieves (mm)	% Passing by Weight	
		Selected Gradation	Local Specification, [8]
3/4"	19	100	100
1/2"	12.5	95	90-100
3/8"	9.5	88	76-90
No.4	4.75	65	44-74
No.8	2.36	39	28-58
No.50	0.300	14	5-21
No.200	0.075	5	4-10

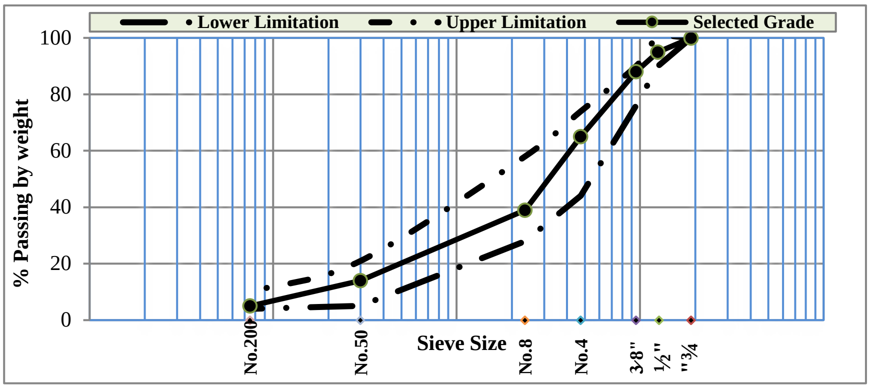

Fig. 1. Aggregate gradation curve for wearing course.

Table 3. Properties of coarse and fine aggregates.

No.	Test	ASTM Specification No.	Results
Coarse Aggregate			
1	Apparent Specific Gravity	C-127	2.643
2	Bulk Specific Gravity	C-127	2.563
3	Water Absorption,%	C-127	0.322
4	Los Angeles Abrasion,%	C-131	20
5	So_3 , %	BS-812	0.4
Fine Aggregate			
1	Apparent Specific Gravity	C-128	2.742
2	Bulk Specific Gravity	C-128	2.689
3	Water Absorption,%	C-128	0.69
4	So_3 , %	BS-812	0.5
5	Sand Equivalent	AASHTO T176	55

Fig. 2. Forms of the styrene- butadiene- styrene (SBS) polymer.

2.2. Experimental works

The experiments in this study began with the selection of 4.7% optimum asphalt content for the control mixture and the SBS modified mixtures to ensure consistency.

2.2.1. Laboratory mixing of asphalt binder with SBS polymer

First, the asphalt binder was subjected to heating at 135 ^{o}C to achieve a free flow state before adding SBS polymer. The mixture was stirred continuously at a high-speed and maintained in the oven at 180 ^{o}C until expansion was noticed [9]. Having achieved expansion, the mixture was placed in the shearing machine for 40 min under high-speed of 2500 rpm [10] before being returned to the oven at 160 ^{o}C for another 2 h of continuous development. Finally, the mixture was removed subjected to various tests. In this work, 4 %, 4.5 %, and 5% of SBS polymer were blended with asphalt binder.

2.2.2. Asphalt binder tests

The effect of SBS on the asphalt cement was evaluated using the asphalt tests. This test was performed following the ASTM specification (refer to Table 4). Additionally, the vulnerability of the modified bitumen to temperature was determined in terms of the penetration index (PI) based on the achieved results from the penetration and softening point tests. Furthermore, the rotational viscosity test (shown in Fig. 3) was employed to investigate the high-temperature performance of the bitumen after SBS modification. Rotational viscosity (RV) was determined at 135 ^{o}C and 165 ^{o}C, respectively according to ASTM standard.

After the measurements, the ideal mixing and compaction temperature (MCT) ranges of the binders in flexible pavement application were calculated using the viscosity test results. This issue will be discussed in the upcoming subsections.

Table 4. Asphalt binder tests.

Test	Units	Test Conditions	Standard
Penetration	0.1 mm	100 gm., 25 ^{o}C, 5 sec.	ASTM D5
Softening Point	^{o}C	4 ^{o}C	ASTM D-36
Rotational Viscosity	Pa. sec	135 ^{o}C & 165 ^{o}C	ASTM D4402

Fig. 3. Rotational viscometer.

2.2.3. Marshall test

The preparation of the specimens for the Marshall test followed the specified Marshall test method (ASTM D6927-15). The asphalt, at a temperature of about 145 ^{o}C, was mixed with the heated blended aggregates for about 3 min to achieve a homogenous mixture. The loose asphalt mixtures were molded to cylindrical samples of height = 63.5 mm and diameter = 101.6 mm using Marshall cylindrical molds. The Marshall samples were produced using 75 blows of Marshall Hammer on either side of the mold. Some of these samples are shown in Fig. 4. Next, the samples were placed in a water bath (60 ^{o}C) and allowed for 30-40 min before being tested. The tests were performed by applying a vertical diametrically load on the samples at a regular loading rate of 50.8 mm/min. until the peak load is attained. This test was performed using the Marshall apparatus.

Fig. 4. Marshall specimens.

2.2.4. Index of retained strength test

The detrimental effect of moisture on the compressive strength (CS) of the asphaltic mixtures was evaluated by obtaining the numerical index of the reduced CS. this was achieved by matching the CS of the standard conditioned asphalt mixtures with the CS of the modified mixture which has been dipped in water as follows:

$$IRS = \frac{S_2}{S_1} \times 100 \tag{1}$$

where, *IRS* = index of retained strength (%), S_1 = CS of dry mixtures (kPa), and S_2 = CS of water-dipped mixtures (kPa).

Six cylindrical samples of diameter = 101.6 mm and height = 101.6 mm were made for each targeted mixture variable following the recommended ASTM D-1074, 2014 procedure. One out of the three specimens for each mixture served as the control (tested without immersing in water; stored in air bath for 4 h at 25±1ºC prior to the application of an axial load at the load rate of 5.08 mm per min). The failure load for this control sample was recorded as S_1. The remaining 2 specimens for each mixture were immersed in a water bath at 60 ºC for 24 hr. before being transferred to another water bath at 25 ºC for 2 hr. The aim of this process is to acclimatize the samples to the test condition prior to the application of the same load condition. The failure load for the test specimens was recorded as S_2. A minimum *IRS* value of 70% was specified by the Iraqi specification.

3. Results and Discussion

3.1. Temperature sensitivity

Being that the physical properties of SBS modifiers and asphalt material differed, it is believed that the SBS would impact significant changes in the properties of asphalt when mixed together. Temperature sensitivity is one of the important parameters for understanding the failures of asphalt pavement. This is attributed to its role as the major indicator of asphalt performance. Hence, it is necessary to investigate the temperature sensitivity of the modified asphalt mixtures [11]. Figure 5 showed the asphalts' penetration grade to decrease with increases in the percentage of SBS modifier at a fixed temperature. There was also a decrease in the slope of the penetration-temperature curve which suggests a decrease in the sensitivity of the asphalt to temperature. Contrarily, Fig. 6 showed an increase in the asphalts' penetration index with the addition of SBS modifier. The decrease in penetration and increase in softening point (see Fig. 7) with increases in the modifier content clearly indicate that SBS polymer has a stiffening effect on bitumen.

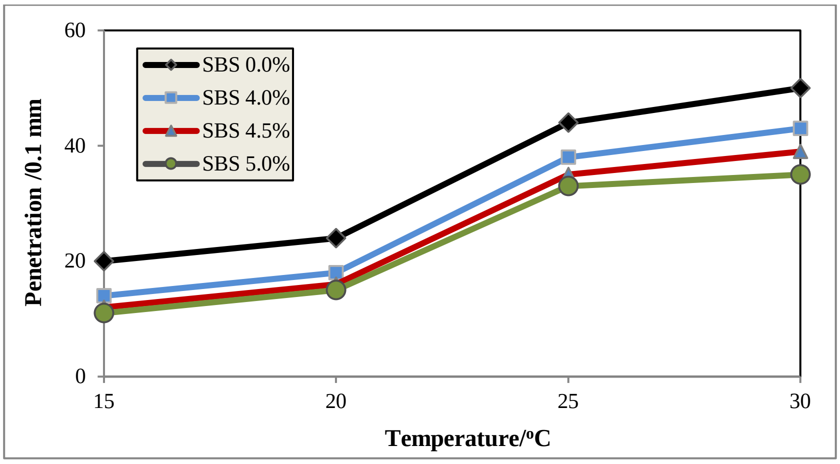

Fig. 5. SBS content effect on penetration grade.

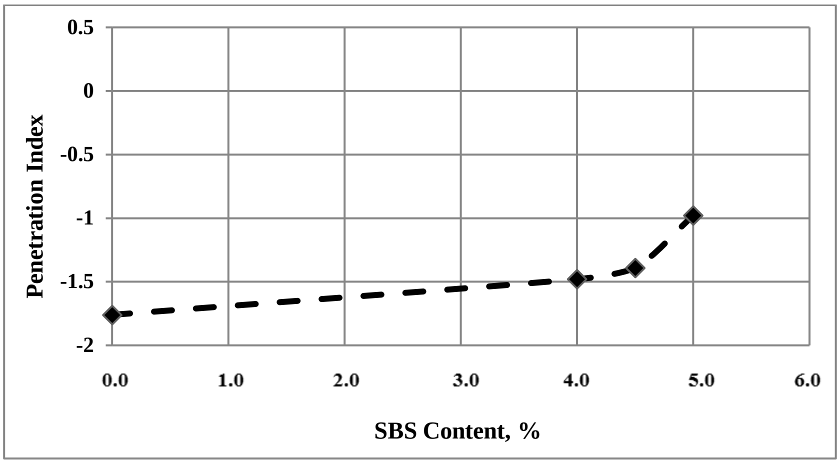

Fig. 6. SBS content effect on penetration index.

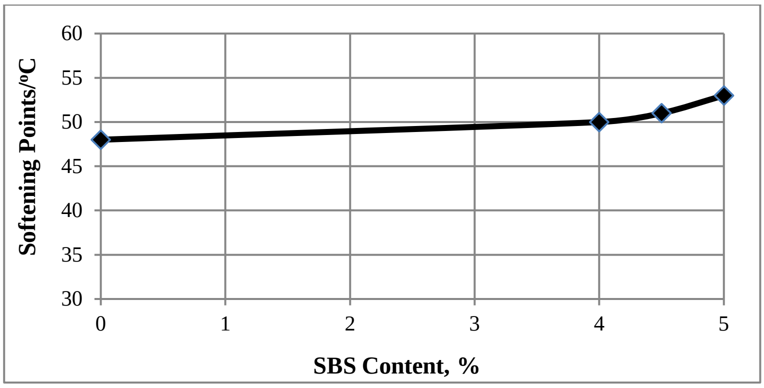

Fig. 7. SBS content effect on softening point.

3.2. High-temperature performance

The performance of asphalt pavement under high temperature is an important indicator [12]. Similarly, the viscosity of asphalt binder at elevated temperatures reflects the ability of the binder to be pumped and compacted. Therefore, SHRP guideline states that unaged asphalt binders' viscosity must not exceed 3 Pa.sec at 135 ^{o}C for the convenience of storage and pumping in the construction period [13]. Figure 8 showed the viscosities of the virgin and three SBS modified binders with different SBS polymer concentrations at 135 ^{o}C. A general trend was observed in the results (Fig. 8); the viscosity of the virgin and SBS polymer modified binders increases gradually and fulfilled SHRP guidelines as the maximum viscosity of asphalt binder was no greater than 3 Pa.sec at 135 ^{o}C. The results show an improvement in the performance of asphalt at high temperature with the incorporation of SBS modifier. This translates to improved stability of asphalt mixture at high temperatures, as well as the anti-rutting capability of asphalt pavement.

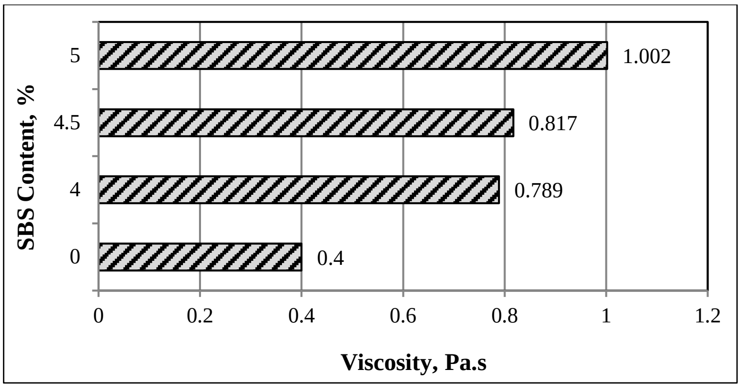

Fig. 8. Viscosities of the virgin asphalt and SBS modified asphalt at 135 ^{o}C.

3.3. Marshall stability and flow

In the wearing course design, one of the significant properties for the performance of asphalt mixtures is the stability as it portrays the capability of the asphalt to resist rutting and shoving under traffic. As shown in Fig. 9, the SBS modified asphalt mixtures showed improved Marshall Stability as their Marshall Stability values increased with the SBS percentage. The highest stability value (21.8%) was achieved by asphalt mixtures modified with 5% SBS compared to the control mixture. Marshall Stability value of the SBS modified and control asphalt mixtures were higher than the minimum of the Iraqi specification requirement, which is 7 kN [8].

As shown in Fig. 10., The flow of the SBS modified asphalt mixtures is higher than the control asphalt mixture and the flow values of all mixtures are between 2-4 mm, and that meet the specification requirement criteria [8].

Moreover, Marshall Stability and flow results in this work are conformable with the finding in the previous studies by Obaid [6] and Al-Shaybani [14].

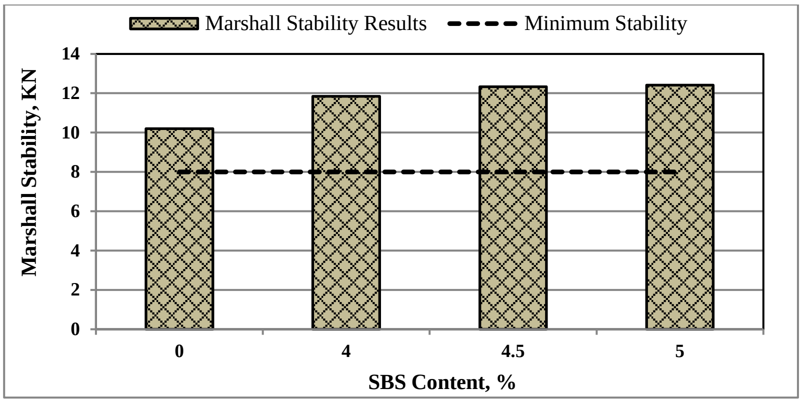

Fig. 9. SBS content effect on Marshall stability.

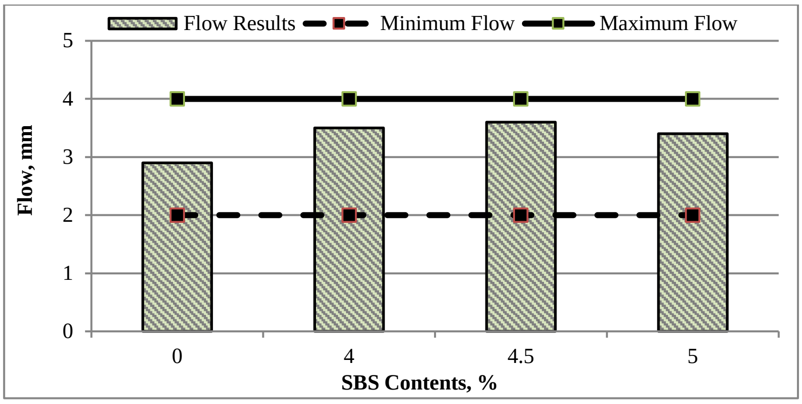

Fig. 10. SBS content effect on Marshall flow.

3.4. Index of retained strength

Moisture damage results from the interaction of moisture with asphalt binder, as well as due to the adhesion of aggregates within asphalt mixtures. This interaction can reduce the attachment of asphalt binder to the aggregate (known as stripping) and this can cause several forms of distress in the asphalt mixture, such as rutting. To reduce the influence of moisture damage on asphalt mixture and develop its resistance, many methods are used for this reason. One of these ways is using SBS polymer as an asphalt modifying material. The SBS polymer tends to change the physical nature of bitumen.

To investigate the effect of SBS on the resistance of the asphalt to moisture damage, the relationship between the SBS content of the mixture and its *IRS* is presented in Fig. 11. From the figure, the control mixture has an *IRS* of 68% which is less than the recommended minimum limit of 70%. However, the modified mixtures achieved higher *IRS* as the SBS content increases. Evidently, the SBS modified asphalt mixtures had a higher resistance to moisture damage due to their higher *IRS* percentage compared to the control mixture. This implies that the durability of these mixtures against environmental effects is higher and they can resist the applied loads efficiently, furthermore, this finding is compatible with the results in the previous study by Obaid [6].

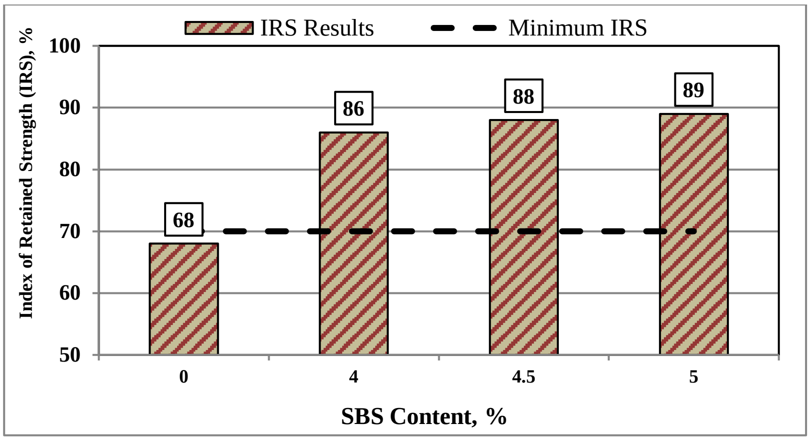

Fig. 11. SBS content effect on *IRS*.

3.5. Effect of SBS modifier on mixing and compaction temperatures (MCT)

The MCT of modified asphalts is vital in the construction process. Hence, it is necessary to choose these in the specified range since any wrong temperature selection (below or above the standard) can cause either leaching of asphalt from the mixture (when higher than the recommended) or poor coating of the aggregate particles (when lower than the recommended) [15].

Table 5 presents the MCT of the SBS modified asphalt mixture. The table showed an increase in the mixing temperature of the SBS modified asphalt as the SBS content increases. This is due to the increase in the modified asphalts' viscosity as the SBS content increases, thereby increasing the required MCT.

Table 5. MCT ranges.

SBS Modifier Content, %	Mixing Temperature Range, °C	Compaction Temperature Range, °C
0.0	164-170	156-160
4.0	168-173	157-162
4.5	169-175	159-163
5.0	171-176	163-166

4. Conclusions

Based on the results of this study, it can be concluded that:

- SBS modification increased the binder consistency by decreasing the penetration and increasing the softening point. It also reduced the sensitivity of bitumen to temperature as evidenced by the improved penetration index.
- The viscosity of the virgin and SBS polymer modified binders increased gradually and achieved the 3 Pa.sec at 135 °C requirement as per Superpave binder specification, thereby improving the stability of the asphalt mixture to high-temperature and increasing its anti-rutting ability.
- The asphalt mixtures modified with 4%, 4.5%, and 5% SBS had a higher Marshall Stability and flow compared to the control mixture.

- The modification of asphalt using different SBS contents increased the IRS of the resulting asphalt mixtures. The control mixture achieved an *IRS* value of 68% while the SBS modified asphalt mixtures achieved *IRS* value of 89% a 5% SBS content. This implies that these mixtures possess high resistance to environmental effects, as well as good load resistance.
- The MCT of modified asphalts increases with the percentage of SBS in the mixtures. Therefore, there is a positive relationship between MCT and SBS content in modified asphalt mixtures

Nomenclatures

IRS	Index of retained strength, %
S_1	Compressive strength of dry mixture, kpa
S_2	Compressive strength of water-dipped mixture, kpa

Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
AC	Asphalt Cement
ASTM	American Society for Testing and Materials
CS	Compressive Strength
EPDM	Ethylene Propylene
EVA	Ethyl-Vinyl-Acetate
HMA	Hot Mix Asphalt
MCT	Mixing and Compaction Temperature
PI	Penetration Index
PMB	Polymer Modified Bitumen
PVC	Polyvinyl Chloride
RV	Rotational Viscosity
SBR	Styrene Butadiene Rubber
SBS	Styrene-Butadiene-Styrene
SHRP	Strategic Highway Research Program

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