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Marshall Performance and Volumetric Properties of Styrene-Butadiene-Styrene Modified Asphalt Mixtures

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Abstract

The durability of asphalt pavement is associated with the properties and performance of the binder. This work-study intended to understand the impact of blending Styrene-Butadiene-Styrene (SBS) to conventional asphalt concrete mixtures and calculating the Optimum Asphalt Content (OAC) for conventional mixture also; compare the performance between SBS modified with the conventional mixture. Two different kinds of asphalt penetration grades, A.C. (40-50) and A.C. (60-70), were improved with 2.5 and 3.5% SBS polymer, respectively. Marshall properties were determined in this work. Optimum Asphalt Content (OAC) was 4.93 and 5.1% by weight of mixture for A.C. (40-50) and (60-70), respectively. Marshall properties results show an increase in the stability value by 8.65 and 20.19% for A.C. (40-50) with 2.5 and 3.5% of SBS, respectively. And an increase by 9.32 and 20.61% for A.C. (60-70) with 2.5 and 3.5% of SBS respectively. Furthermore, the results indicate a decrease in Marshall flow by 14.7 and 26.47% for A.C. (40-50) with 2.5 and 3.5% SBS respectively and a decrease by 10.46 and 21.21% for A.C. (60-70) with 2.5 and 3.5% SBS respectively. Other Marshall properties were also calculated. Moreover, Blending SBS polymers to conventional asphalt mixtures produces a better performance to asphalt binder and better Marshall properties, which provides a great solution to Iraqi road problems affected by temperature and high traffic load, including less maintenance.

Keywords: Optimum Asphalt Content (OAC); Styrene-Butadiene-Styrene (SBS); Marshall Test; Volumetric Properties.

1. Introduction

Polymers and other additives are widely used to alter and enhance the asphalt cement properties, leading to an improvement asphalt mixture result. Polymers come in a variety of forms, including acrylic, elastomers, and fibres [1]. Since the 1980s, bitumen polymer modification was widely used to reduce bitumen resistance to various temperatures, allowing for drooping in typical failure techniques such as rutting and cracking [2] because of its good engineering properties and economy. SBS has been commonly used in bitumen alteration [3]. As a result, SBS can increase and expand bitumen's elasticity, making it the most suitable polymer for bitumen modification. Polymers also improve the efficiency of asphalt binders [4]. Polymer adjustment of asphalt has been a more fundamental process for treating road distresses for heavy loads, high traffic levels, and tire pressures has required user followers to examine polymer adjustment for binder asphalt application for a long time [5].

Hamdou et al. (2014) studied the influence of polymers (four types) on asphalt mixture with various asphalt content. The results show a reduction in permanent deformation, also produce development in the resilient modulus

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and more resistance to temperature [6]. High temperatures most often cause pavement deformation. The ideal binder should have consistent low-temperature susceptibility properties across the ambient temperature spectrum; thus, adding SBS polymer reduces the viscosity-temperature of bitumen in the ambit of 0-100 ^{o}C, increasing asphalt resistance to rutting [7, 8].

Isacsson and Zeng (1997), looked at the rheological properties of SBS copolymer changed bitumen and discovered that increasing the SBS percentage from 2 to 6% by asphalt weight led to that a marked improvement in the asphalt cement properties [9]. Stuart (1990) studied the effect of SBS on aggregate–asphalt interface adhesion force and discovered that adding SBS polymers increases adhesion force and increases bonding between aggregate and asphalt [10].

Pasandín et al. (2016) study properties of modified asphalt with SBS by adding seven percentages (0.5, 1.0, 1.5, 2.0, 2.5, 3.0, and 3.5) % by the asphalt weight of, and found that the SBS-modified binder mixtures improved Marshall Properties while also increasing moisture damage protection. The hot mix of modified asphalt, which contains 2.5% SBS by asphalt weight, improved Marshall's limitations and moisture resistance [11].

Also, when compared to control mixtures, Haider A. Obaid (2015) investigated the influence of SBS on moisture damage resistance in various asphalt mixtures. He concluded that modified asphalt with an ambit (0.5-4%) of SBS has excellent properties, such as Air voids, Marshall Stability, and increasing compressive strength for unconditioned and conditioned mixtures at different content [12].

The SBS-rich phase forms, a rubbery supporting network is created in the blended bitumen, which produced the Heightened complex modulus and viscosity enhanced elastic response and development cracking resistance at low temperatures of SBS blended bitumen [13], also produced growth in rheological properties such as increase the softening point, viscosity and decrease the penetration grade [14, 15]. Figure 1 shows Fluorescent images of SBS modified asphalt with various contents of SBS [16].

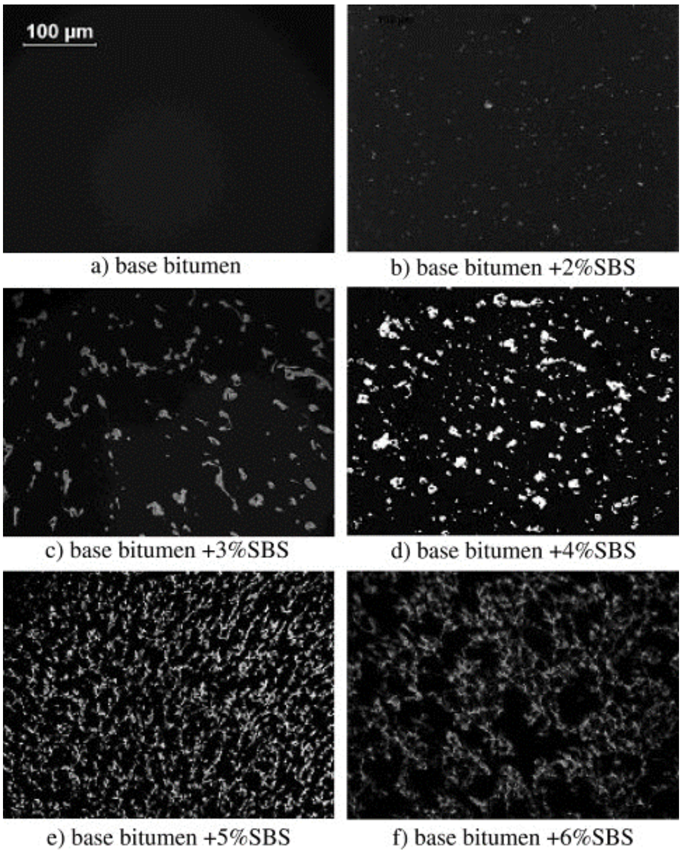

Figure 1. Fluorescent images of SBS modified bitumen with various contents [16]

The conventional tests signify shows that the stiffness of bitumen increases with the addition of SBS Polymer into pure bitumen asphalt, and a significant reduction in temperature susceptibilities of bitumen asphalt take place. That indicates that SBS modified binders can especially be used in regions with high temperatures [17].

Leng et al. (2018) studied the influence of modified asphalt with SBS and concluded that adding SBS leads to a reduction in penetration from 59 to 55 mm, the softening point increased from 56 ^{o}C to 70 ^{o}C and suggested that SBS additives lead to upgrade hardness, stiffness, water-resistance, and ductility of asphalt [18].

Adding SBS to asphalt binder will produce a better asphalt mixture, including increasing asphalt viscosity, increasing film thickness and water resistance to water damage [10, 11]. Although the optimal SBS value with reasonable conclusion 3% but even those 3.5, 4% show decent results, the impact of the SBS on binder at this ambit softly alterations the properties and performance of the asphalt binder mixture [19]. Polymer adjusted bituminous mixtures have been discovered to have the most significant potential for effective road construction utilization to improve the pavement's longevity and service length or reduce the road layer thickness or base thickness [20]. SBS also decreased the sensitivity to ageing and sunlight, which leads to improvement in anti-rutting performance and forming hard carbide films of surface layer [21-23].

SBS in asphalt would increase production cost, but the increased cost will be justified because the overall maintenance cost will decrease once the road construction is completed. As a result, the blend of increasing cost and reducing maintenance appears to be more cost-efficient than the lower cost at the start of the project but altitude maintenance costs. The modification of bitumen would improve performance for a more extended period on heavily trafficked roads with less maintenance access. The purpose of this research is to evaluate the impact of blending various SBS content to conventional asphalt on Marshall properties, for wearing course layer of asphalt pavement with two types asphalt grades A.C. (40-50) and A.C. (60-70), also; compare the results of modified asphalt with control mixture of asphalt pavement and discase the results.

2. Materials and Methods

Figure 2 shows the steps of work developed in this research.

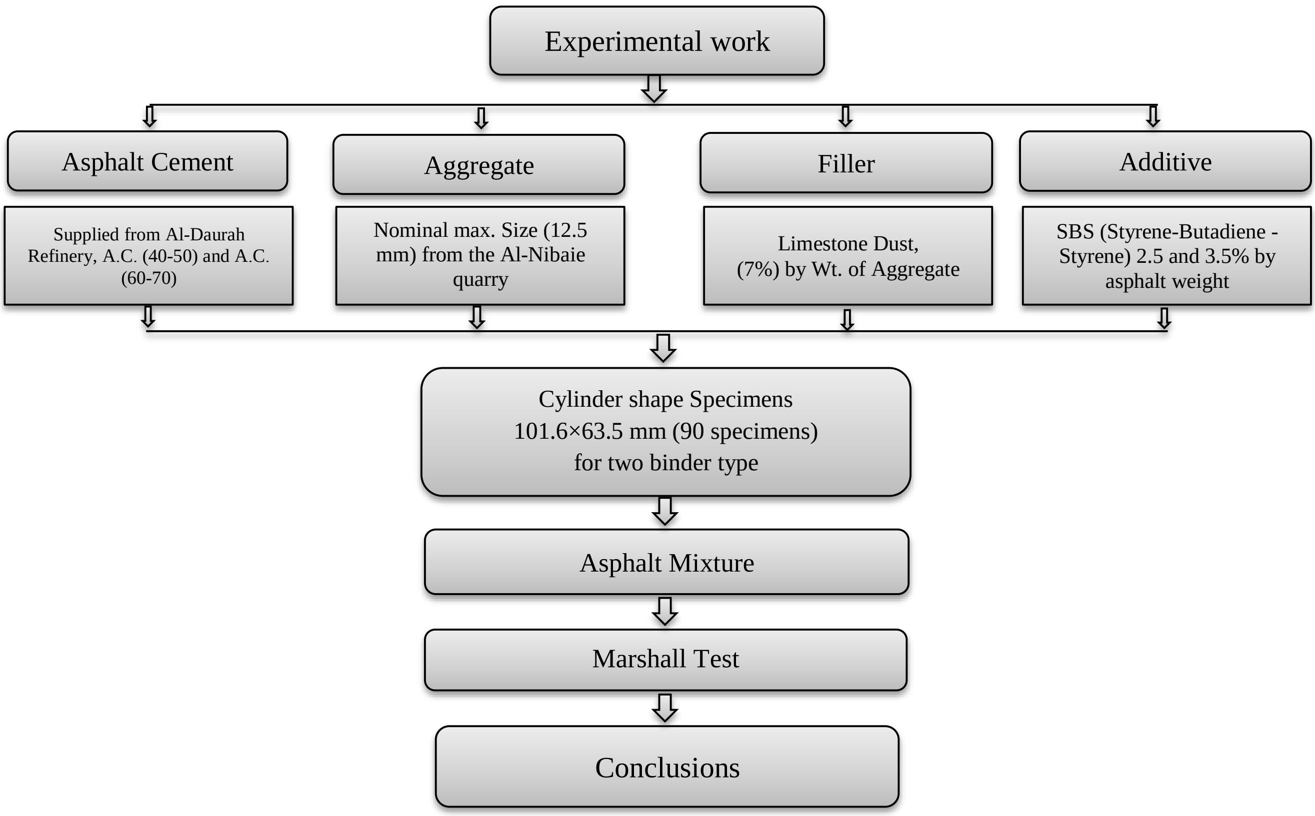

Figure 2. Flow chart of the methodology

The laboratory work included asphalt binder conventional test for virgin and modified asphalt cement. Asphalt concrete specimens were made for the Marshall test to calculate the optimum asphalt and Marshall Test properties. Such as stability and flow values. Moreover, the attributes of volume were calculated to meet Iraqi requirements. The asphalt mixture that was used was formed to match the wearing course specified with the maximum size aggregate 12.5 mm. Two grades of the binder were used 40-50 and 60-70. SBS was added to asphalt with 2.5 and 3.5 percentages by asphalt weight for the two asphalt grades.

2.1. Asphalt Cement

Regarding hot mix asphalt mixtures, two grades of asphalt binder were utilized. A.C. (40-50) and (60-70) grades were provided from Al-Dura petroleum Factory. The physical features of two grades of binder can be shown in Tables 1 and 2. The results tests satisfy the specifications set out by the State Corporation for Roads and Bridges (SCRB R/9, 2003) [24].

Table 1. Physical properties of A.C. 40-50

Test	Results	SCRB Specification [24]	ASTM Designation No. [25]
Penetration (25^{0}C, 100 gm, and 5sec)	44 (0.1 mm)	40 - 50	D-5
Softening point, (Ring and Ball)	51 (^{0}C)	-------	D-36
Ductility, 25 ^{0} C and 5 cm/minute	152 (cm)	≥ 100	D-113
Specific Gravity @ 25 ^{0} C	1.048	-------	D-70
Flash point, (Cleveland Open Cup)	294 (^{0}C)	>232	D-92

Table 2. Physical properties of A.C. 60-70

Test	Results	SCRB Specification [24]	ASTM Designation No. [25]
Penetration (25^{0}C, 100 gm, and 5sec)	65 (0.1 mm)	60 - 70	D-5
Softening point, (Ring and Ball)	45 (^{0}C)	-------	D-36
Ductility, 25 ^{0} C and 5 cm/minute	171 (cm)	≥ 100	D-113
Specific Gravity @ 25 ^{0} C	1.039	-------	D-70
Flash point, (Cleveland Open Cup)	249 (^{0}C)	>232	D-92

2.2. Coarse and Fine Aggregate

The coarse crushed aggregate utilized to prepare hot asphalt mixtures in this research is supplied from Al-Nibaie quarry. It retains on sieve No. 4. The fine aggregate was bought from the Ashour government Company (particle size between No.4 and No. 200). Aggregate properties were conformed to Laboratory evaluation. The physical properties of aggregates are shown in Table 3.

Table 3. The physical characteristics of Aggregates

Property	ASTM Designation No. [25]	Test Results	
		Fine	Coarse
Specific Gravity (Bulk)	C-128& C-127	2.63	2.581
Specific Gravity (Apparent)	C-128& C-127	2.624	2.614
Water Absorption Percent	C-128& C-127	0.961	0.56
Per cent Wear	C-131	----	15.9

2.3. Mineral Filler

The limestone dust used in this study to prepare the asphalt concrete mixture is passed sieve No 200. (0.075 mm). A lime factory in Karbala provides it. The physical features of the mineral filler are shown in Table 4.

Table 4. The physical properties of the limestone dust

Property	Result
Passing sieve No. 200	95%
Specific gravity	2.73

2.4. SBS Additive (Styrene-Butadiene-Styrene)

SBS is a thermoplastic polymer that increases asphalt pavement's overall consistency. SBS softens at high temperatures, making it simple to apply and blend with asphalt binder. SBS was brought from the Kraton Company in France and added to asphalt cement to produced asphalt mixture with good properties. Table 5 shows the physical and chemical features of SBS, and Figure 3 shows the SBS that was used in this work.

Table 5. Properties of SBS

Property	Results
Physical state	solid
Density (Kg/m^3)	1247
Melting point (^{o}C)	197
Colour	yellow

Figure 3. SBS used in experimental models

2.5. Selection of Aggregates Gradation

The gradation aggregate in this research was selected according to the specifications recommended by the State Commission of Roads and Bridges (SCRB) [24]. Figure 4 depicts the aggregate gradation chosen due to the wearing course, with an aggregate nominal maximum size of 12.5 mm.

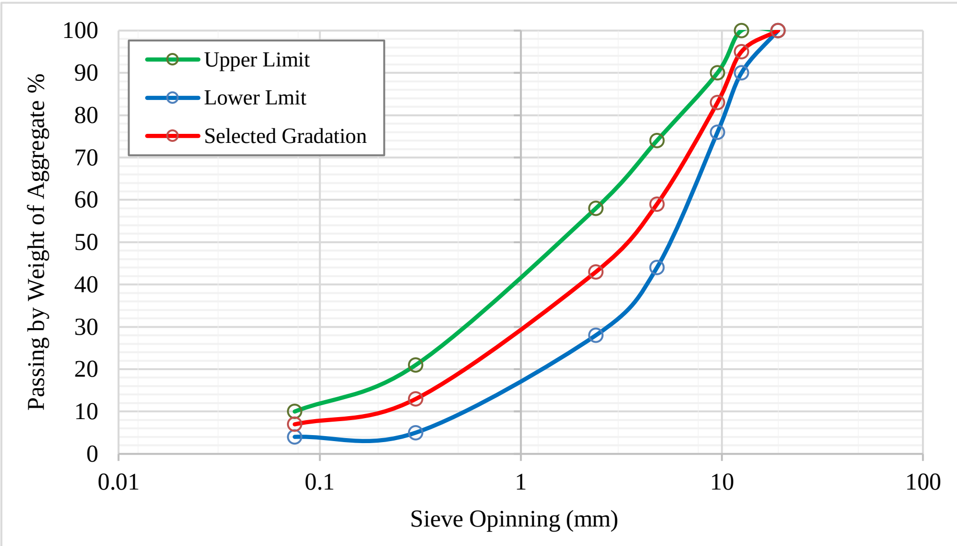

Figure 4. Aggregates gradation for the wearing course

3. Marshall Test

This test intended to find the (OAC), stability, flow, density, and air voids for asphalt concrete mixture by cylindrical shape specimens that exhibited 4 inches in diameter and 2.5 inches in height. The bulk specific gravity and density were determined in compliance with ASTMD-2726. The per cent of air voids were calculated for each specimen according to ASTM D3203, the per cent of air voids were calculated from Equation 1:

$$\% \text{ Air Voids} = [1 - \text{Bulk sp. gr.} / \text{Max. Theo. sp.gr.}] \times 100 \tag{1}$$

Where:

Bulk sp. gr. ➡ Bulk Specific Gravity.

Max. Theo. sp. gr. ➡ Maximum Theoretical Specific Gravity of the Mixture.

For each specimen, Marshall Stability and flow values were determined using the procedure outlined in ASTM D6927.

3.1. Preparation of Conventional and Modified Mixture

To obtain asphalt concrete mixture according to wearing course specifications. The aggregate was sieved and separated for each size, then mix with the filler to obtain suitable gradation meeting with specifications. This combined filler and aggregate were the temperature raised to 155 °C, while asphalt was being heated at the same time to a temperature that results in a kinematic viscosity of (170±20) centistokes. The aggregate with a filler and different amounts of virgin asphalt binder in the mix for about two minutes ensures that asphalt binder coated aggregates surface.

For blended asphalt binder, the SBS was added to the virgin binder with 2.5 and 3.5% by asphalt weight due to conclusions of [11, 12], which study and calculate that the optimum content of SBS that blended with asphalt binder. SBS was powdered in a strong mixer before mixing with virgin asphalt, then mixed with asphalt cement at a temperature of 170 °C for 30 min. and stirring (on a hot plate) to achieve a homogenous blend. Figure 5 and 6 shows a group of Marshall specimens and Marshall test respectively.

After that, specimens in a template placed to phlegmatic at the natural temperature of the room for one day and then removed from a template using an extractor. And put in a water bath at 60 °C for a half-hour, then pressed on the side surface at a fixed rate of (50.8. mm/min) 2 in/min, until reached the failure load.

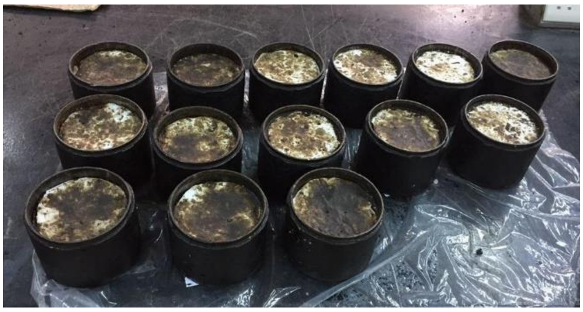

Figure 5. Group of Marshall Specimens

Figure 6. Marshall test

4. Results and Discussions

4.1. Marshall Test

To estimate optimum asphalt content (OAC) for asphalt mixtures. Many results of Marshalls test should be obtained (Marshall stability, density-voids analysis, and flow) with using aggregate (12.5 mm nominal maximum size gradation) for wearing course, limestone dust (seven percent by weight of the total aggregate), and five various asphalt contents for each (40-50) and (60-70) penetration grade ranging from 4 to 6 percent (by a total of mix weight) with a raise of 0.5 percent. For modified asphalt, two percent of SBS (2.5 and 3.5) by weight of asphalt have been added to the virgin asphalt.

The OAC was 4.93% for virgin A.C. (40-50), 4.86% for modified A.C. (40-50) with 2.5% SBS, (4.8) % for modified A.C. (40-50) with 3.5% SBS. The OAC for conventional A.C. 60-70 was 5.1%, 4.95% for modified A.C. 60-70 with 2.5% SBS, 4.88% for modified A.C. 60-70 with 3.5% SBS, adding SBS to asphalt lead to increase in asphalt viscosity that causing reduction in aggregate absorption and increasing in free asphalt in the mixture [11]. The Marshall assets for OAC met all of the checks and met Iraq's requirements (SCRB, 2003) [24].

The results of Marshall stability show that the stability was increased by 8.65 and 20.19% in comparison to a traditional mixture A.C. (40-50) when it applies to modified asphalt A.C. (40-50) with 2.5 and 3.5% SBS, respectively. The stability was increased by 8.9 and 19% compared to a traditional mixture A.C. (60-70) when it applies to modified asphalt A.C. (60-70) with 2.5 and 3.5% SBS. This increase in stability can be explained as adding more SBS to asphalt binder leads to development in the performance of thermo-rheological state and stiffness related to increase of asphalt viscosity [11, 12]. The effect of SBS on Marshall stability is depicted in Figure 7.

For Marshall flow, the results show that the Marshall Flow was dropped by 14.7 and 26.47% in comparison to a traditional mixture A.C. (40-50) when it applies to modified asphalt A.C. (40-50) with 2.5 and 3.5% SBS respectively. The flow was decreased by 10.46 and 21.21% compared to a traditional mixture A.C. (60-70) when it applies to modified asphalt A.C. (60-70) with 2.5 and 3.5% SBS. This decrease in flow can be explained as SBS's improved adhesion and cohesion between asphalt and aggregate, causing increment in asphalt viscosity [11, 20]. Figure 8 shows the impact of SBS on the Marshall flow.

For bulk density, the results show that the bulk density was increased by 0.6 and 0.86% in comparison to a traditional mixture A.C. (40-50) when it applies to modified asphalt A.C. (40-50) with 2.5 and 3.5% SBS, respectively. The bulk density increased by 0.39 and 0.91% compared to a traditional mixture A.C. (60-70) when applies to modified asphalt A.C. (60- 70) with 2.5 and 3.5% SBS, respectively. Adding SBS to asphalt binder led to a rise in the viscosity of modified asphalt, which is responsible for decreasing aggregate absorption, causing drops in aggregate demand, leading to a reduction in bulk density [12], as shown in Figure 9.

For Air Voids, the results show that A.V. % was decreased by 2.93 and 4.8% compared to a traditional mixture A.C. (40-50) when it applies to modified asphalt A.C. (40-50) with 2.5 and 3.5% SBS, respectively. The A.V. % was decreased by 5.5, 9.64 % compared to a traditional mixture A.C. (60-70) when it applies to modified asphalt A.C. (60-70) with 2.5 and 3.5% SBS respectively, as shown in Figure 10.

The results show the VFA % was decreased by 1.33 and 3.33% compared to a traditional mixture A.C. (40-50) when it applies to modified asphalt A.C. (40-50) with 2.5 and 3.5% SBS respectively. The VFA % was decreased by 3.84 and 6.02 % compared to a traditional mixture A.C. (60-70) when it applies to modified asphalt A.C. (60-70) with 2.5 and 3.5% SBS respectively. That results can be shown in Figure 11.

The results show the VMA % was increased by 2.61 and 3.62% compared to a traditional mixture A.C. (40-50) when it applies to modified asphalt A.C. (40-50) with 2.5 and 3.5% SBS, respectively. The VMA was increased by 3.8 and 4.33% compared to a traditional mixture A.C. (60-70) when it applies to modified asphalt A.C. (60-70) with 2.5 and 3.5% SBS respectively, as shown in Figure 12.

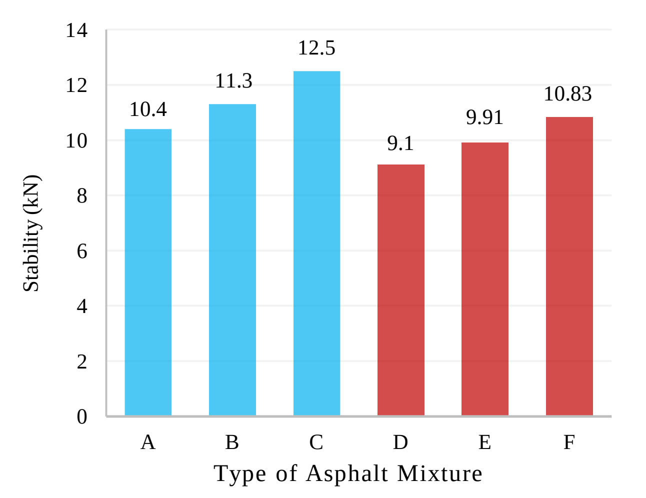

Figure 7. Effect of SBS on the Marshall Stability

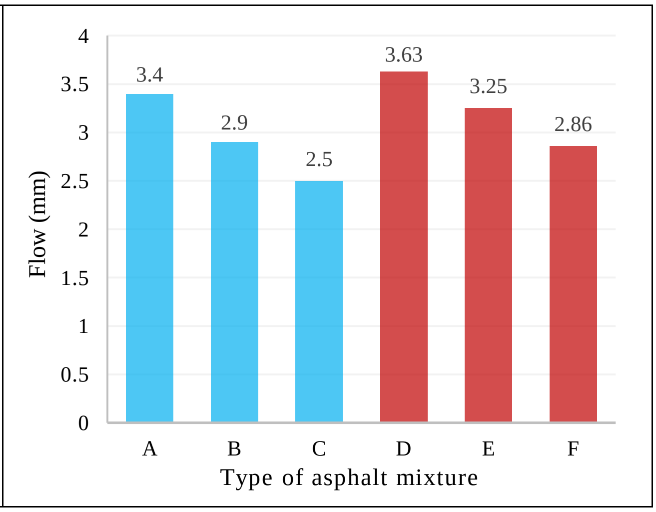

Figure 8. Effect of SBS on the Marshall Flow

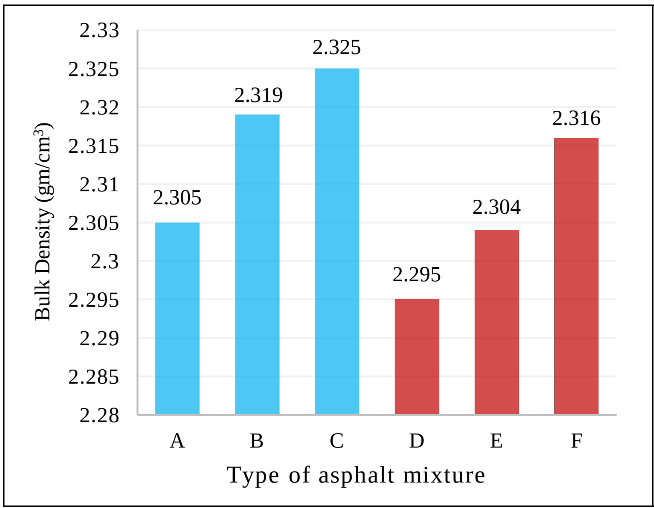

Figure 9. Effect SBS on the Bulk Density

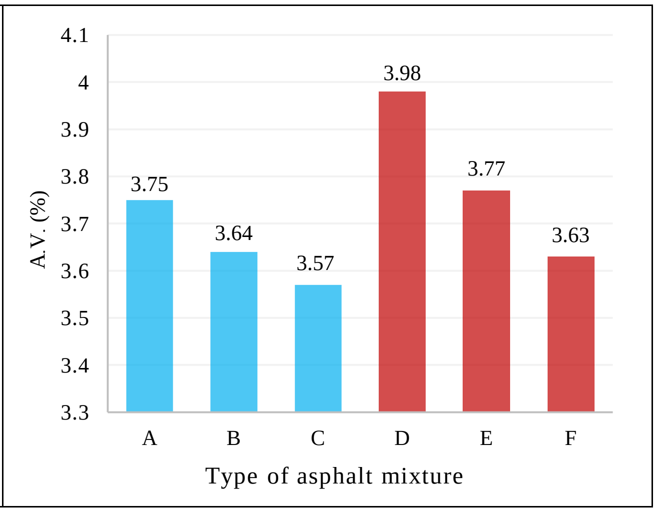

Figure 10. Effect SBS on the Air Voids

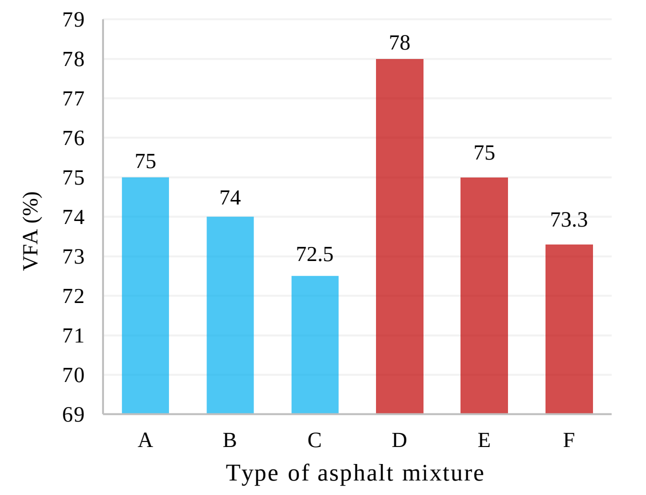

Figure 11. Effect SBS on the voids filled with asphalt

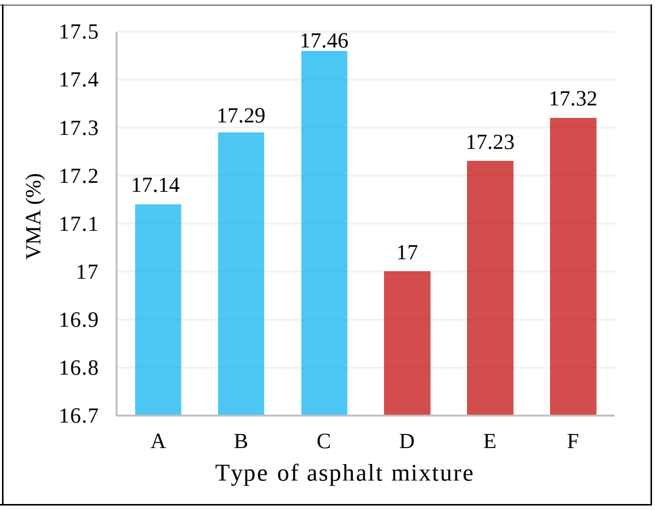

Figure 12. Effect of SBS on the voids in mineral aggregate

Where A represents A.C. (40-50), B represents modified A.C. (40-50) with 2.5% SBS, C represents modified A.C. (40-50) with 3.5% SBS, D represents to A.C. (60-70), E represents to modified A.C. (60-70) with 2.5% SBS and F represents to modified A.C. (60-70) with 3.5% SBS. Finally, the effect of blending SBS polymer to asphalt leads to an increase in the thermo-rheological performance of asphalt, which leads to an increase in asphalt viscosity that is responsible for dropping aggregate absorption to the binder, causing increment in free asphalt in the total mixture and more voids in mineral aggregates [26].

5. Conclusions

This research study the performance of blend asphalt with various contents of SBS polymer as Compliant with the test program, the points below are concluded:

- The (OAC) for modified asphalt A.C. (40-50) with 2.5 and 3.5% SBS decreased by 1.42 and 2.63% compared with (OAC) of conventional asphalt A.C. (40-50), respectively. The OAC for modified asphalt A.C. (60-70) with 2.5 and 3.5% SBS decreased by 2.94 and 4.31% compared with (OAC) of conventional asphalt A.C. (60-70), respectively.
- The results of Marshall Stability increased by 8.65 and 20.19% of modified asphalt A.C. (40-50) with 2.5 and 3.5% SBS compared with conventional mixtures A.C. (40-50) respectively. The results of Marshall Stability were improved by 9.32 and 20.61% of modified asphalt A.C. (60-70) with 2.5 and 3.5% SBS compared with conventional mixtures A.C. (60-70), respectively.
- The results of Marshall Flow decreased by 14.7 and 26.47% of modified asphalt A.C. (40-50) with 2.5 and 3.5% SBS compared with conventional mixtures A.C. (40-50), respectively. The results of Marshall Flow improved by 10.46 and 21.21% of modified asphalt A.C. (60-70) with 2.5 and 3.5% SBS compared with conventional mixtures A.C. (60-70), respectively.
- The bulk density is raised when asphalt content increases until it reaches the peak, then begins to Famish. The additional bitumen forming more films surround the aggregates and a propensity to drive the aggregate further apart, therefore producing lower density. The bulk specific gravity increases when the aggregate demand for asphalt decreases due to increasing viscosity, leading to less absorption to the asphalt binder.
- The drop in A.V.% was found because the addition of SBS increased the solid mass fraction and the rigidity of asphalt and produced a modified binder with more brittle and viscous. When asphalt viscosity increased, absorption of aggregate to asphalt decreased and produced asphalt mixture with thicker asphalt coating aggregates. This operation was responsible for the variation of A.V.% in the asphalt mixture.
- The decrease in voids filled with asphalt percent occurred because of increased asphalt binder viscosity due to blending more SBS polymers, which finally decreased aggregate absorption to asphalt binder.
- Modified asphalt produced better Marshall properties. The increase in SBS polymer leads to improved Marshall's properties, A.C. (40-50) for conventional asphalt and modified asphalt showing more sensitivity to SBS polymer and more improvement to Marshall properties.

Blending SBS polymers with asphalt leads to development in asphalt properties that produce great solutions for pavement problems such as (rutting, moisture damage, temperature, …) also produced development in rheological properties (softening point and viscosity). This study recommended using SBS to develop the performance of pavement roads in Iraq.

6. Declarations

6.1. Author Contributions

Conceptualization, M.Q.I.; methodology, M.Q.I.; software, S.A.J.; writing—original draft preparation, S.A.J.; writing—review and editing, M.Q.I.; supervision, M.Q.I.; All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available in article.

6.3. Funding

The Ministry of Higher Education and Scientific Research and Baghdad University, College of Engineering's, Civil Engineering Department, sponsored this study.

6.4. Conflicts of Interest

The authors declare no conflict of interest.

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