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Influence of SBS Polymer on Asphalt Binder Characteristics and Moisture Resistance of Mixtures

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ABSTRACT

This study investigates the effect of Styrene-Butadiene-Styrene (SBS) polymer on asphalt binder properties and the performance of asphalt mixtures. Binder modification was evaluated through penetration, softening point, and rotational viscosity tests, showing that SBS addition enhanced binder stiffness, increased temperature resistance, and improved workability during mixing and compaction. Marshall tests indicated a progressive increase in stability and a gradual reduction in flow with higher SBS content, reflecting improved load-bearing capacity and reduced susceptibility to permanent deformation. Indirect tensile strength (ITS) tests under dry and wet conditions demonstrated enhanced moisture resistance in SBS-modified mixtures. Overall, SBS modification significantly improves both the rheological characteristics of the binder and the mechanical performance of asphalt mixtures, with the highest improvement observed at the 4% SBS content, providing an effective balance between stiffness, deformation resistance, workability, and moisture susceptibility.

1. Introduction

Asphalt is a vital component of modern infrastructure, widely used in road construction due to its durability and adaptability to various environmental conditions. Extracted from crude oil through distillation, asphalt's physical and chemical properties are closely related to the source of the crude oil and the refining methods applied. The need to enhance asphalt performance through modification technologies, particularly polymer modification, has increased because of the limited availability of high-quality crude oil and technical constraints in refining processes. Modern road networks play a crucial role in supporting urban growth and facilitating transportation [1]. However, environmental factors and design limitations can reduce the long-term performance of asphalt pavements, often manifested as cracks, ruts, and structural failures.

Despite advances in pavement design, conventional asphalt binders face inherent limitations, particularly under heavy traffic loads and extreme temperature variations. Therefore, research has focused on improving the mechanical and rheological properties of asphalt binders by incorporating polymers. These additives increase elasticity, reduce cracking, and prevent permanent deformation, effectively extending pavement service life. Developing optimal polymer-modified asphalt requires a thorough understanding of phase compatibility, thermal stability, aging behavior, as well as economic and environmental considerations .Among various polymers, Styrene-Butadiene-Styrene (SBS) has proven to be highly effective due to its unique triblock copolymer structure, which imparts superior

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elasticity and mechanical strength. Studies have shown that SBS can improve asphalt binder performance by 30–60% compared to unmodified binders. The effectiveness of SBS depends on factors such as polymer concentration, the physicochemical characteristics of the base asphalt, and mixing conditions, emphasizing the importance of a performance-based design that reflects real service conditions .Over the past four decades, traditional asphalt pavements have shown insufficient resistance to increasing traffic volumes and axle loads, resulting in reduced service life and higher maintenance costs. Research efforts have focused on enhancing the interaction between asphalt and mineral aggregates, as well as improving binder-aggregate adhesion and durability. Polymer modification has emerged as one of the most successful enhancement techniques [2,3]. By incorporating polymers into asphalt through mechanical or chemical methods, polymer-modified asphalt binders (PMBs) allow engineers to tailor binder properties to specific traffic and climatic conditions. various polymers including elastomers [4,5], crumb rubber [6, 7], waste plastics [8], and nanomaterials [9] have been used to enhance asphalt rheology. These modifications increase asphalt resistance to rutting at high temperatures and thermal cracking at low temperatures, thereby significantly extending pavement lifespan [10,11]. Polymers generally enhance viscosity, elasticity, and thermal stability, leading to better load distribution and reduced structural stress [12,13].

The effectiveness of polymer-modified binders primarily depends on two factors:

- Material characteristics, including the grade and source of base asphalt, as well as polymer type and concentration [14].
- The method used to incorporate the polymer into the binder [15,16].

Previous studies have shown that polymer modification raises the softening point, reduces penetration, and improves overall binder performance [17]. Furthermore, polymer addition enhances the mechanical properties of asphalt mixtures, leading to improved rutting resistance, fatigue performance, and resilient modulus [18]. For instance [19], compared mechanical properties of polymer-modified asphalt mixtures in the Riyadh region. Similarly, Carlos et al. (2021) investigated highly modified asphalt (HMA) and conventional polymer-modified asphalt under different binder and mastic conditions, demonstrating that HMA provided superior long-term performance compared to conventional [20].

The main objective of this study is to compare conventional and polymer-modified asphalt through laboratory experiments, evaluating physical and mechanical enhancements.

2. Materials

2.1. Asphalt Cement

One type of asphalt cement with a penetration grade of (40–50), obtained from the Nasiriyah refinery, was used in this study. The basic physical properties of this binder were determined through a series of laboratory tests conducted in accordance with ASTM standards [31-33], and the results were evaluated against the specifications of the State Corporation for Roads and Bridges (SCRB, 2003). The physical characteristics of the binder, along with the testing devices used, are summarized in Table 1 and illustrated in Figure 1.

2.2 Coarse and Fine Aggregates

The coarse crushed aggregate used in this study was supplied from the Al-Nebaie quarry. For the asphalt wearing course, the size of the coarse aggregate ranged from 19 mm to 4.75 mm, while the fine aggregate passed the No. 4 sieve and was retained on the No. 200 sieve, in accordance with SCRB specifications (SCRB/R9, 2003). The physical properties of both fine and coarse aggregates are presented in Table (2) .

2.3 Mineral Filler

Ordinary Portland Cement (OPC) was used in this study as the mineral filler. The filler is a non-plastic material that passes through sieve No. 200 . The bulk specific gravity of the cement was taken as 3.14 g/cm.

2.4 Selection of Aggregates Gradation

The aggregate and filler gradation was selected in accordance with the SCRB (2003) specifications [21], with a nominal maximum size of 12.5 mm corresponding to wearing course Type IIIA. The selected aggregate gradation is presented in Table 3 , and Fig.2 shows the gradation curve of the aggregate used for wearing course.

Table 1: Physical properties of asphalt binder grade (40-50)

Test	Unit	ASTM Designation NO.	Asphalt Binder (40-50)	SCRB Specification
Penetration (25C, 100g, 5s) 0.1mm	1/10 mm	D-5	41	
Softeningpoint,°C	(°C)	D-36	49	
RotationalViscometer@135,165,°C Pa.s	Pa.s	D-4402	0.569 0.139	3 MAX

Table 2: Physical properties of coarse and fine aggregate

Coarse Aggregate	Coarse Aggregate		Fine Aggregate	
	ASTM2010	Result	ASTM 2010	Result
Bulk Specific Gravity	C-127	2.583	C-128	2.581
Apparent Specific Gravity	C-127	2.758	C-128	2.592
Percent Water Absorption	C-127	0.543	C-128	0.698
Loss Angles Absorption	C-131	17.9	-------	-------

Table 3: Selected Aggregate Gradation (12.5 mm Nominal Maximum Size, Wearing Course Type IIIA) (SCRB/R9, 2003).

No. Sieve	Sieve Opening(mm)	% passing by weight	
		Selected Gradation%	Specification Range%
3/4"	19	100	100
1/2"	12.5	95	90-100
3/8"	9.5	83	76-90
No.4	4.75	59	44-74
No.8	2.36	43	28-58
No.50	0.3	13	5-21
No.200	0.075	7	4-10

A **b** **c**

Figure 1. Testing devices used (a)Penetration Test , (b) Softening Point Test, (c) Rotational Viscosity Test.

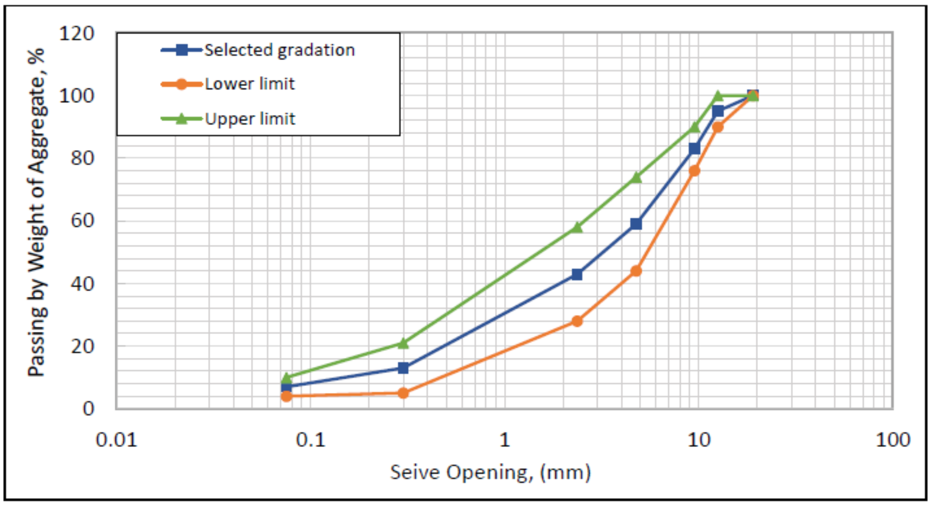

Figure 2. Gradation curve of Wearing layer.

2.5 Polymer additives

The selection of a suitable polymer for asphalt modification must take into account factors such as durability, adhesion, and local availability. Although many polymers are commercially available, this study focused on styrene–butadiene–styrene (SBS) due to its proven effectiveness in asphalt paving mixtures. SBS is a block copolymer widely regarded as one of the most efficient modifiers for bitumen. Its ability to form cross-linked structures with the base asphalt enhances elasticity, resistance to aging, and high-temperature performance of the binder [22]. These characteristics make SBS an attractive option for improving the functional properties of asphalt binders. Figure 3 illustrates the polymer material used in this study, and Table 4 presents the physical properties of the SBS polymer. SBS was incorporated into the asphalt binder at concentrations of 3%, 3.5%, and 4% by weight to evaluate its influence on the modified binder properties.

Figure 3. SBS polymer

Table 4: Properties of (SBS) Polymer

Property	Results
Physical state	Solid
Density (Kg/m3)	1247
Color	White
Melting point	197

Figure 4. Blending process

Table 5: Physical properties of (PMB)

Test	Unit	ASTM Designation No.	Test Result			SCRB Specification
			3% SBS	3.5% SBS	4% SBS	
Penetration (25 C, 100 g, 5 s), 0.1 mm	1/10 mm	D-5	38	37	36	
Softening point, °C	(°C)	D-36	60	60	65	
Rotational Viscometer @135, 165, °C Pa. s	Pa .s	D-4402	1.01 0 0.23 3	1.057 0.247	1.09 4 0.25 8	3 MAX

3.Experimental Work

3.1 Preparation of Polymer Modified Bitumen (PMB)

Three types of polymer-modified asphalt binders were prepared by incorporating styrene–butadiene–styrene (SBS) at concentrations of 3%, 3.5%, and 4% by weight of the base asphalt. The base binder was first heated to 175–180 °C to reduce its viscosity, facilitating efficient polymer dispersion while preventing thermal degradation of the SBS [23]. A locally developed high-shear mixer was then operated at a rotational speed of 2000 rpm, and the SBS pellets were gradually added while continuous shear mixing was maintained for 2–3 h. This high-energy mixing ensured uniform polymer dispersion and prevented pellet agglomeration, thereby promoting the formation of a stable three-dimensional polymer network within the binder. The resulting network significantly improved the binder’s elasticity, thermal stability, and resistance to aging [24]. Figure 4 illustrates the blending process, and Table 5 presents the physical properties of the polymer-modified binder (PMB). Our findings indicate that incorporating 4% SBS polymer into asphalt mixtures provides the most effective balance of physical, mechanical, and thermal stability compared with both lower and higher contents. fluorescence microscopy has been employed to examine the microstructural distribution of SBS within bitumen. Their analysis revealed that at concentrations between 4% and 5%, the polymer was uniformly and densely dispersed, which enhanced the interaction between SBS and the binder and contributed to improved mechanical and thermal properties. When the content exceeded 6%, certain individual properties continued to improve; however, excessive viscosity and reduced thermal stability were observed, which may negatively affect the overall performance of the mixture under service conditions. Therefore, the evidence from this study highlights 4% SBS as an optimum content, where homogeneous distribution is achieved without compromising viscosity or thermal stability, making it a highly effective dosage for modifying dense asphalt mixtures[25] .

3.2. Marshall test

The Marshall method was employed to design asphalt mixtures and to determine the optimum asphalt content (OAC). The OAC was identified by averaging three criteria: maximum stability, maximum density, and 4% air voids in the total mixture, as shown in Figure 4. This method is widely applied in asphalt concrete design to satisfy the requirements of the State specifications (SCRB/R9, 2003). Cylindrical specimens with a diameter of 101.6 mm and a height of 63.5 mm were prepared in accordance with ASTM D6927[26]. To establish the OAC, control mixtures were first prepared with binder contents of 4.0%, 4.5%, 5.0%, 5.5%, and 6.0%, using 1140 g of aggregate per specimen. The mixtures were designed for a surface wearing course. Type IIIA aggregate gradation was selected, positioned at the midpoint between the upper and lower limits of the Iraqi specification, with a maximum aggregate size of 19 mm, a nominal maximum size of 12.5 mm, and 7% mineral filler. According to Iraqi standards, a minimum Marshall stability of 8 kN is required, ensuring that the mixture is suitable for high-traffic applications. For the modified mixtures, the same aggregate gradation and a binder content of 4.8% were adopted, while varying the additive contents. Polymer concentrations of 3%, 3.5%, and 4% SBS were selected. Before mixing, the aggregates, filler, and molds were preheated in an oven at 165 °C. After sieving and grading, the aggregate and filler were blended to achieve the target gradation. The mixture was then heated to 155 °C, and the asphalt binder was conditioned until it reached a kinematic viscosity of 170 ± 20 cSt. The binder was subsequently added to the hot aggregate–filler blend and mixed for approximately two minutes to ensure a uniform coating of aggregate particles. The prepared mixtures were placed into preheated molds and left to cool at room temperature for 24 h before being demolded using an extractor. Prior to testing, the specimens were conditioned in a water bath at 60 °C for 30 min. The Marshall test was then conducted by applying a compressive load at a constant rate of 50.8 mm/min (2 in/min) until failure. The maximum load at failure (Marshall stability) and the corresponding deformation (flow value) were recorded. Figures 5 and 6 illustrate the prepared Marshall specimens, as well as the testing procedure and curves used to determine the OAC.

a **b** **C** **d**

Figure 5. Marshall test procedure (a) Preparing mixture, (b) Group of Samples, (c) Water Bath, (d)Test Runing

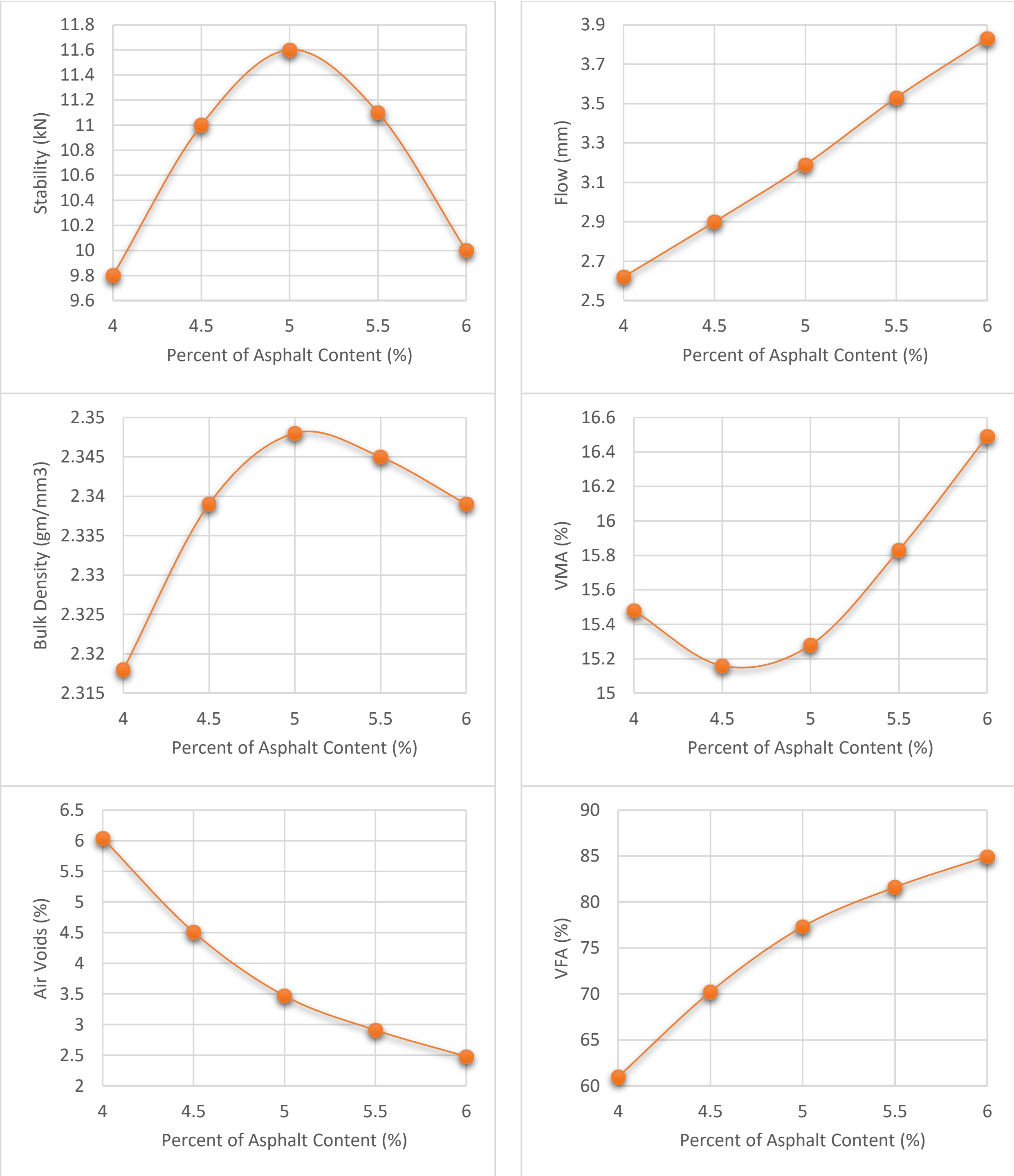

Figure 6. Marshall properties to obtain (OAC)

3.3. Indirect Tensile Strength Test

The ITS test was conducted to evaluate the tensile properties of the asphalt mixtures, following the ASTM D6931 standard [27]. This test provides important information about the mixtures' tensile strength and fatigue behavior.In the ITS test, cylindrical specimens were placed along their diametrical axis and subjected to a constant deformation rate of 5.1 cm/min at 25°C until failure occurred along the vertical diameter, as illustrated in Figures 7 and 5.The indirect tensile strength (ITS) of each specimen was calculated using the following equation:

$$ITS = 2P/\pi DT$$

Where:

D: is the sample's diameter in(cm)

T: is the sample's height or thickness in(cm)

P: is the peak or maximum load in KN.

a b c

Figure 7. Indirect Tensile Strength (a) ITS Specimen , (b) Test Running , (c) Specimen after Test

3.4. Tensile Strength Ratio:

Six Marshall specimens were prepared for each mix and compacted to achieve 7 ± 1% air voids using different numbers of blows per face, following the Marshall procedure the first three specimens were subjected to indirect tensile strength (ITS) testing being conditioned in a water bath at 25 °C for at least 30 minutes. The average ITS value of these unconditioned samples (ITS_{unconditioned}) was calculated They remaining three specimens were conditioned to simulate moisture damage. They were placed in a vacuum container filled with potable water at 25 °C. A partial vacuum of 30 mm Hg was applied for 5–10 minutes to achieve approximately 70% saturation. Specimens were then wrapped in plastic bags and stored in a freezer at -18 ± 3 °C for at least 16 hours. After freezing, the plastic bags were removed, and the specimens were allowed to thaw at room temperature for 2 hours.

The water bath was maintained at 60 ± 1 °C throughout the day. Indirect tensile strength tests were then conducted on these moisture-conditioned specimens following 1 hour of storage at 25 °C in a water bath. Figure 8 (a, b, c) illustrates the conditioning process for TSR test the TSR was calculated according to ASTM D 4867-09 [28] as follows:

the TSR value must be at least 0.8 (80%) to satisfy specification requirements

$$TSR = Std / Stm$$

Where:

For unconditioned samples

Std = average ITS, For moisture-conditioned samples kPa.

Stm = average ITS, kPa

a **b** **c**

Figure 8. Tensile Strength Ratio test Procedure (a)Vacuum process , (b) Freezing of specimen, (c) water bath @60°C for 24 h.

4. Results and Discussion

4.1 Physical characteristics of bitumen and bitumen treated with SBS

The physical properties of the asphalt binder were evaluated for the control binder and for binders modified with different percentages of additive, as summarized in Table .1 and Table.5 . The penetration results showed a progressive decrease with increasing additive content, reflecting enhanced binder stiffness. Specifically, the binder modified with 3% additive exhibited a penetration decrease of approximately 7.3% compared to the control, while 3.5% and 4% additive resulted in reductions of about 9.8% and 12.2%, respectively. The softening point increased notably with the addition of additives, indicating improved resistance to high temperatures.

The 3% and 3.5% modified binders showed an increase of around 22.4% relative to the control, and the 4% binder demonstrated the highest increase of approximately 32.7%. Viscosity measurements at elevated temperatures further confirmed the effect of the additives. At 135°C, viscosity increased by 77.4%, 85.7%, and 92.3% for the 3%, 3.5%, and 4% modified binders, respectively, compared to the control. Similarly, at 165°C, viscosity increased by 67.6%, 77.7%, and 85.6% for the same additive percentages. These results , clearly depicted in Figures 9 ,10 and , 11demonstrate that the additives significantly improved binder stiffness, thermal resistance, and internal stability, and that the magnitude of improvement is directly correlated with the additive percentage. Overall, the findings correspond closely with previous work on SBS-modified asphalt binders, supporting the observed increase in stiffness and viscosity with higher additive content [29,30].

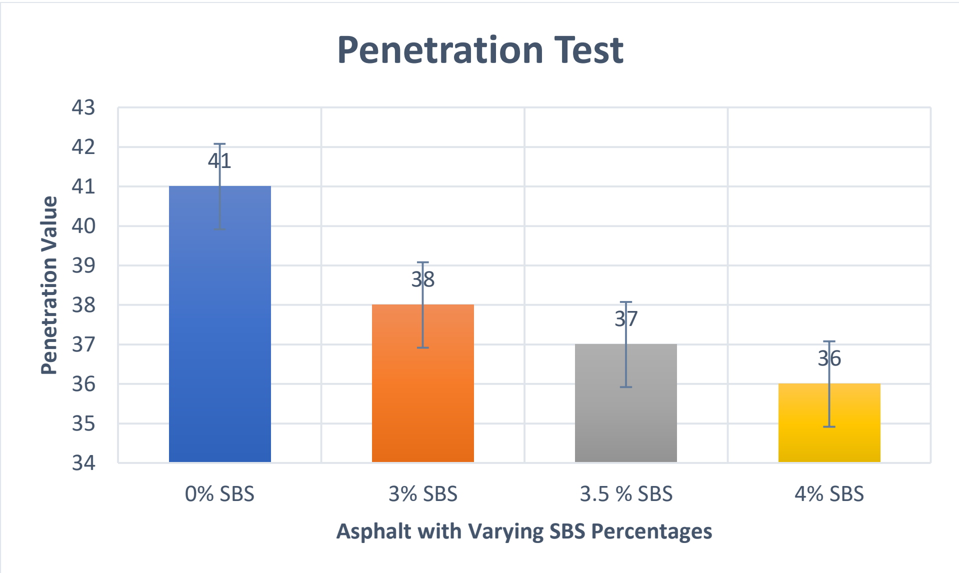

Figure 9. Penetration of neat and polymer modified asphalt binders.

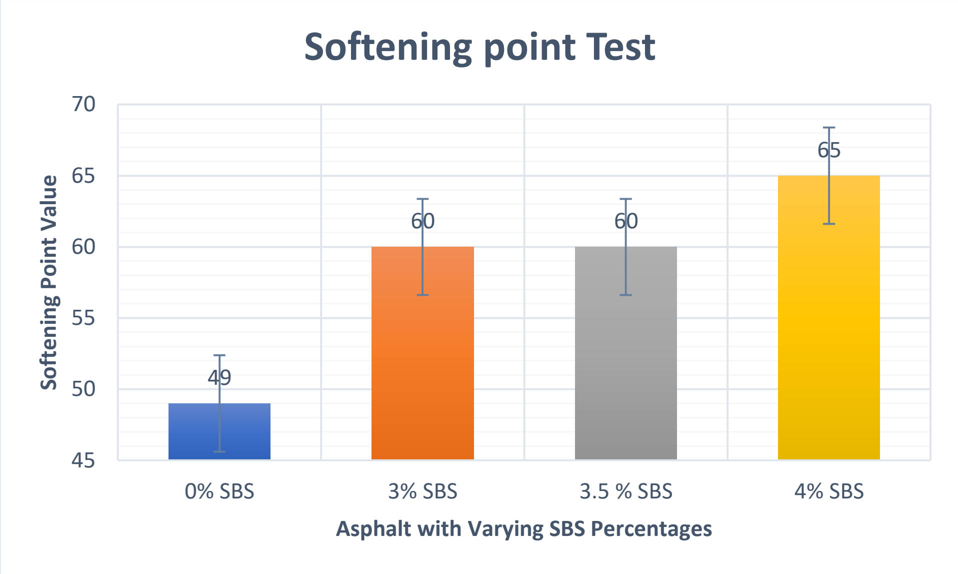

Figure10. The softening point values for polymer-modified asphalt and asphalt.

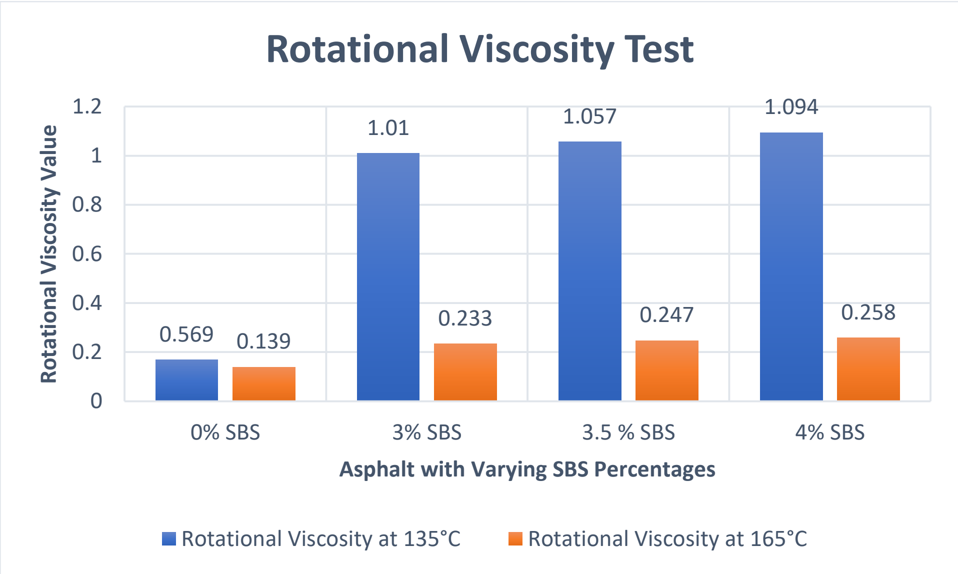

Figure11. The variation of rotational viscosity.

4.2 Effect of SBS Polymer Content on Tensile Strength Ratio (TSR)

The mechanical performance and moisture susceptibility of the asphalt mixtures were evaluated through indirect tensile strength (ITS) and tensile strength ratio (TSR) tests. The ITS results demonstrated a clear improvement in the tensile strength of the SBS-modified mixtures compared to the control, indicating enhanced resistance to cracking under tensile stress. From Figures 12 and 13 the addition of 3%, 3.5%, and 4% SBS led to progressive increases in ITS for unconditioned and conditioned sample .

Similarly, the TSR values showed a consistent improvement in the moisture resistance of the asphalt mixtures with increasing SBS content. Relative to the control mixture, the incorporation of SBS resulted in progressive enhancements in TSR, with observed increases of 2.2% at 3% SBS, 3.9% at 3.5% SBS, and 5.8% at 4% SBS as shown in Figure 14. These findings indicate that higher SBS contents effectively enhance both the mechanical properties and the overall durability of the asphalt mixtures, confirming the efficiency of SBS as a modifying additive for improved performance under environmental conditions.

Overall, the observed improvements in ITS and TSR are consistent with previous studies on SBS-modified asphalt binders which reported similar enhancements in tensile strength and moisture resistance [31].and The detailed ITS and TSR values, including mean and standard deviation for each SBS concentration, are presented in Table (6).

Table 6 ITS and TSR Results for Asphalt Mixtures with Varying SBS Contents

SBS CONTENT	Average ITS (KPa) (Unconditioned)	Average ITS (KPa) (Conditioned)	TSR (%)
0%SBS	**1133 ± 67**	**912 ± 56.3**	**80.5 ± 2.03**
3%SBS	**1223 ± 77**	**1007 ± 69**	**82.4 ± 4.6**
3.5%SBS	**1296 ± 79.4**	**1086 ± 86**	**83.8 ± 3.7**
4%SBS	**1371 ± 75**	**1169 ± 95**	**85.2 ± 2.3**

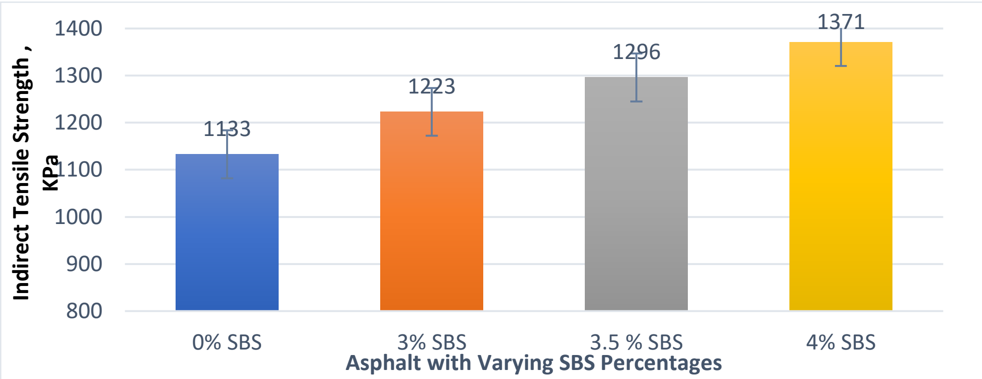

Figure 12. The Indirect tensile strength for the unconditioned sample with different SBS content

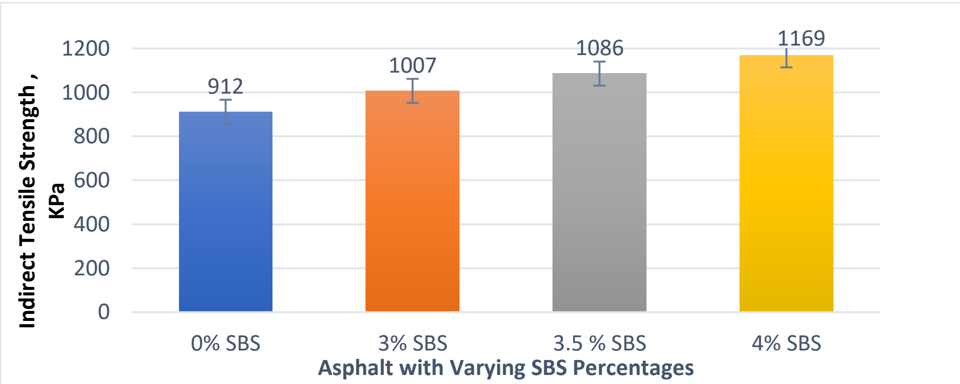

Figure 13. Indirect tensile strength for the conditioned sample with different SBS content

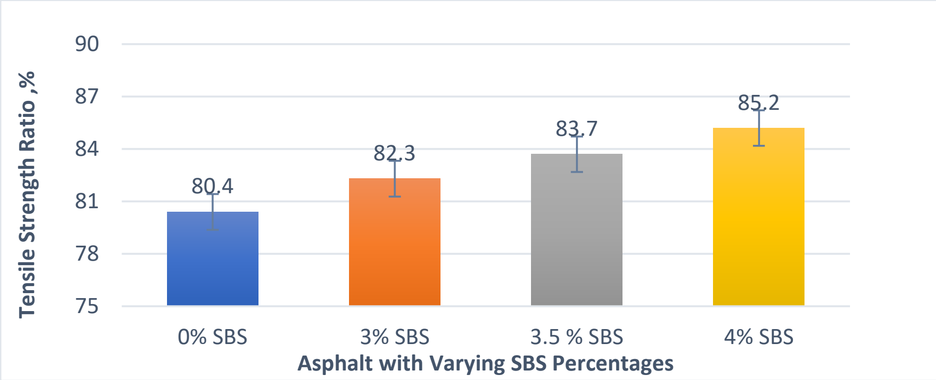

Figure 14. Indirect tensile strength ratio

4.3.Marshall Stability and Flow Test

Marshall Stability and Flow test results are illustrated in Figures 15 and 16 respectively, and summarized in Table 7 . The incorporation of SBS resulted in a steady improvement in stability by about 9.5 ,26.7,34.3% when adding 3,3.5and4% SBS , indicating stronger binder–aggregate cohesion and enhanced structural capacity of the mixtures.

Conversely, the flow values showed a gradual reduction with increasing SBS content, reflecting improved resistance to deformation while preserving the mixture's flexibility within acceptable limits . It is noted that all result are fully compliant with the specification range according to SCRB/R9(2003) [21].

Table 7 Marshall Stability And Flow Test

Mix Design	Stability (KN)	Flow (mm)
0% SBS	**10.5 ± 1.6**	**3.8 ± 0.1**
3%S BS	**11.5 ± 0.6**	**3.8 ± 0.4**
3.5% SBS	**13.3 ± 0.5**	**3.5 ± 0.3**
4% SBS	**14.1 ± 0.5**	**3.1 ± 0.3**

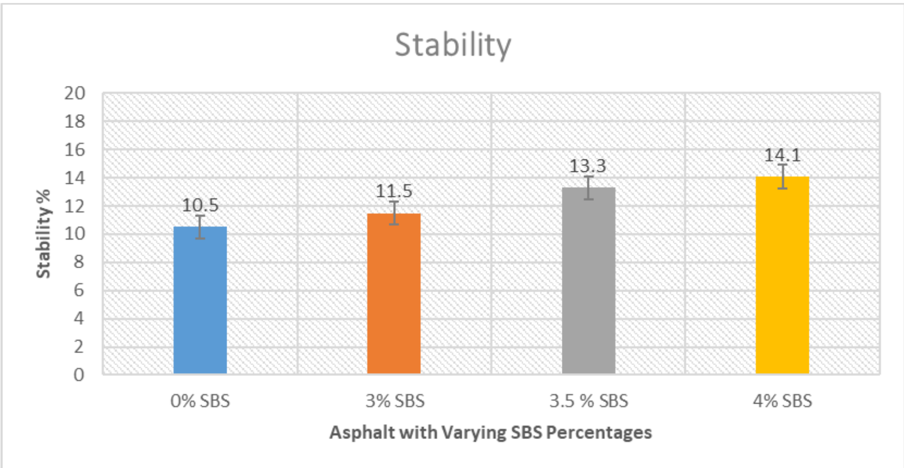

Figure 15. Marshall stability

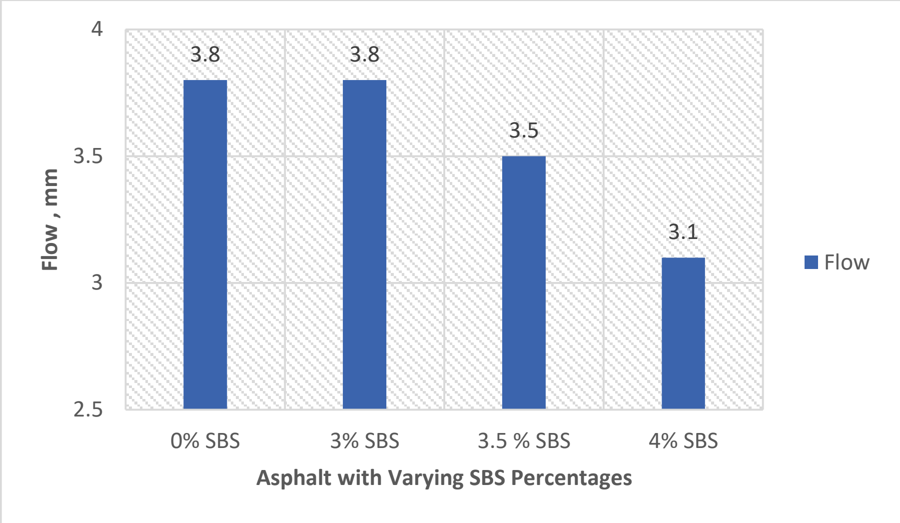

Figure 16. Marshall flow

Table 8 presents a summary of key studies indicate that incorporating approximately 4% SBS generally provides the most effective balance of physical, mechanical, and thermal properties.

Author	**Year**	**Title**	**Main Focus**	**Findings**
Zhang,l.etal.	2017	Effects of SBS Content on the Performance of Modified Asphalt	Effect of SBS content on asphalt mixture performance	Performance improves with increasing SBS content up to a certain limit; 4% provides a good balance of physical and mechanical properties.
Li, H., et al.	2021	Performance Deterioration of SBS-Modified Asphalt Mix: Impact of Elevated Storage Temperature and SBS Concentration	Effect of storage temperature and SBS content on modified mixtures	Moderate SBS contents around 4% exhibit better stability compared to very low or high contents, supporting 4% as optimal.
Kumar, P., et al.	2025	Experimental Study of Performance Enhancement in SBS Modified Asphalt Mixtures	enhancing asphalt mixture properties using SBS	Increasing SBS content enhances stiffness and rutting resistance; 4% achieves a balance to avoid high viscosity or reduced thermal stability.

4. Conclusions

The findings of this study demonstrate that modifying asphalt binders with styrene–butadiene–styrene (SBS) polymer enhances their performance and extends their service life. Among the tested concentrations, 4% SBS by weight of asphalt cement provided the best overall performance and stability of the mixture. The key conclusions drawn from this study are as follows:

1. The penetration values decreased with the incorporation of SBS, reflecting increased binder stiffness. The reductions were 36% for 4% SBS, 37% for 3.5% SBS, and 38% for 3% SBS, respectively.
2. The softening point increased significantly with higher SBS content, enhancing binder performance at elevated temperatures and improving resistance to thermal deformation.
3. The rotational viscosity test revealed a considerable increase in viscosity with SBS addition. This indicates that SBS modification improves binder viscosity and performance characteristics, though it requires higher mixing and compaction temperatures.
4. Increasing the SBS content from 3% to 4% resulted in notable improvements in Marshall stability, demonstrating greater resistance to plastic deformation.
5. The ITS results for both unconditioned and conditioned samples showed enhanced tensile strength and fatigue resistance, with improvements corresponding to higher SBS ratios.
6. TSR values increased progressively with SBS content, ranging from 82.3% at 3% to 85.2% at 4%, thereby confirming improved resistance to moisture damage.

In summary, polymer-modified asphalt, particularly at 4% SBS , substantially improves the rheological and mechanical properties of asphalt binders, making it a promising solution for enhancing pavement durability under increased traffic loads and environmental stressors.

5. Limitations and Future Work

This study provides meaningful insights into the effect of SBS polymer on asphalt binder and mixture performance. However, some inherent limitations remain, which define the scope of this study and highlight directions for future research.

1- Polymer Types: Future research should consider alternative polymers, such as crumb rubber, waste plastics, or nanomaterials, to enable broader comparisons.

2- Long-Term Performance: The study relied on short-term laboratory tests. Field trials and extended aging studies are required to validate the long-term durability and service life of the proposed method.

3- Economic and Environmental Aspects: Cost–benefit analysis and sustainability issues (e.g., recyclability and emissions during production) were not addressed and should be incorporated into future investigations.

4- Study Microstructural Analysis using SEM and Chemical Characterization using FTIR .

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