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DESIGN AND EVALUATION OF ASPHALT SURFACE LAYER USING POLYMER-MODIFIED BITUMEN FOR EXTREME CONDITIONS

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ABSTRACT

Iraq is faced with extreme seasonal temperatures and rapidly growing traffic, so it will be a priority to ensure that the country has resilient road infrastructure. In many cases, traditional asphalt is unable to hold up in such conditions over time and will start to wear out before it should. The result is a demand to upgrade pavement design using innovative enhancement materials, in order to extend the life of pavements and reduce the frequency and cost of maintenance works in hot arid regions. Finally, there are problems with road maintenance systems and periodic monitoring, as there is no reliable, fixed database to assess the surface layer efficiency of various roads periodically. The purpose of the study specifically addresses the asphalt surface layer, given its direct importance in all these problems. Regular bitumen is relatively weak, and the goal is to improve the properties of the asphalt surface mixture through some additives to the bitumen to enhance its properties. The research methodology involves designing an asphalt mixture using RMP and conducting the required laboratory tests. The base bitumen was modified by adding 4.2% SBS polymer in accordance with AASHTO M320 specifications and achieving a PG76-10 performance grade. The results demonstrated improved stress resistance and enhanced Marshall stability, along with reduced permanent deformation and increased resistance to high

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temperatures. It is recommended to adopt this mixture according to the stated proportions, considering the direct variables, each according to the specific requirements of the project conditions.

Keywords: Asphalt surface, Polymer, Bitumen, Pavement Performance, Extreme conditions

INTRODUCTION

Technical requirements and specifications were determined for the asphalt surface layer. The hot asphalt mix was designed using polymerized asphalt binder for the layer. Surface and materials taken from the asphalt plant are used to find the final proportion that can be used in the asphalt mixing plant to produce the asphalt surface layer. A mixture equation for the improved surface layer with polymer-modified asphalt binder was developed and tested to ensure that we achieved a reduction in contraction, deformation, and an increase in cohesion. Although the cost will increase by 20-35%, the road's lifespan will also increase by 10-15 years (Airey, 2004; Amin et al., 2015; Keyf, 2018; Gao et al., 2022; Jexembayeva et al., 2024).

Road pavements require materials capable of withstanding heavy loads and climatic fluctuations to minimize surface distress such as alligator cracking and rutting. The selection of paving materials is strongly influenced by road type and anticipated traffic volume. and problems with road network connectivity, which places greater stress on some roads than others (Li et al., 2022; Kim and Le, 2023; Abujwaid et al., 2026).

For instance, polymer-modified asphalt is commonly preferred for highways, while concrete pavement is recommended in hot climates and areas subjected to frequent heavy truck traffic (Liu, 2015; Li et al., 2022). Numerous researchers have emphasized polymer modification of asphalt as an effective solution, which has led to a significant increase in related studies. It has been widely reported that

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polymers enhance the elasticity of asphalt binders, reducing their sensitivity to temperature variations and consequently improving pavement durability (Liu, 2015; Liu et al., 2025).

The SBS system offers numerous advantages in improving asphalt mixes. It effectively contributes to increasing tensile strength and extending pavement life while reducing permanent deformation. Despite its high efficiency, its high cost and manufacturing precision remain challenges (Ma et al., 2023). On the other hand, the use of EVA polymer has emerged as a flexible alternative characterized by good resistance to chemicals and weathering. It should be noted that its mechanical performance is directly related to the percentage of vinyl acetate in the composition (Mieczkowski et al., 2021; Muldabekova, 2024). As for the environmental aspect, recycled tire rubber (Crum Rubber) has been employed to enhance asphalt flexibility and reduce waste. However, its use requires careful processing to avoid compatibility problems between materials over time (Redelius and Soenen, 2015; Peng et al., 2022; Özcanana et al., 2024). Regarding rheological properties, parameters such as G'/\sin play a pivotal role in measuring the asphalt's resistance. Deformations at high temperatures, while the stiffness modulus and m -value reflect the material's ability to withstand stresses and resist cracking caused by cold or repeated loading. To ensure a homogeneous and highly durable mix, it is generally recommended to add SBS at a rate of 3% and EVA at a rate of 2%-4% of the total asphalt weight (Tang et al., 2013; Wardana and Setiawan, 2022; Xu et al., 2024).

MATERIALS AND METHODS

3.1 Aggregate and filler

Table 1 illustrates the sieve analysis of the medium and fine crushed stone, in addition to crushed and natural sand used in this research. Brija quarries aggregate in Iraq was used in this study. An Iraqi named Kufa ordinary Portland cement (OPC) was used in this study as a filler. The maximum aggregate size of less than

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19mm was used. The mechanical properties of the aggregate, such as crushing percentage, thinning and elongation factor, plasticity, and sand equivalent. were examined in this study, and they are within the standard limits, as shown in Table 1. Aggregate other properties, such as chemical corrosion, clay aggregates, and friable materials (mechanical corrosion), were investigated in this research. According to the test results, they are within the standard limit, as shown in the table.

Table 1. Aggregate and filler properties

Material		Medium crushed stone size	Fine crushed stone size	Crushed sand (0-5) mm	Natural sand (0-5) mm	Cement	Requirements under the Road and Bridge Specifications and Amendments 2003
% Passing	Grading according to AASHTO: T11, T27, T37/20 06						
¾"		97*	100	100	100	100	
½"		47*	100	100	100	100	
3/8"		4	81	100	100	100	
#4		2	12	88	99	100	
#8		1	4	58	94	100	
#50		1	2	19	52	100	
#200		0	1	8.5	2.6	95.5	
Crushing percentage according to the specification ASTM D5821/2017		100	100	–	–	–	90% minimum (one or more broken faces) for the bonding and surface layers
Plasticity guide according to the specification AASHTO T89/2010		–	–	Nothing	Nothing	–	4% maximum
Thinning and elongation factor % according to the specification ASTM D4791/2010		1.2	3	–	–	–	10% maximum (for particle with a length-to-thickness ratio of 1:5)
Sand equivalent % according to the specification AASHTO T176/2008		–	–	51	48	–	45% minimum
Chemical corrosion %		7.2		9.1	–	–	12% maximum using sodium sulfate

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Clay aggregates and friable materials % according to the specification AASHTO T112/2012	0.38	0.44	1.12	1.42	–	3% maximum
Mechanical corrosion % according to specification ASTM C131/2014	24	21	–	–	–	30% maximum

3.2 Bitumen

Polymer styrene-butadiene-styrene (SBS) modified bitumen was used in this research. 4.2% of the polymer-modified bitumen by weight has been added to the base bitumen to meet the performance grading (PG) 76-10 specification. The basic properties of the polymer (SBS) modified bitumen used in this research are shown in

Table 2. From Table 2, it is clear that all the basic properties of the polymer (SBS) modified bitumen are within the standard limit.

Property	Standard	Modified bitumen test result	Requirement
Penetration test 25°C, 100 g, 5sec 0.1 mm	ASTM D5	40	-
Flash Point °C	ASTM D92 & AASHTO T48	309	Min. 230°C, AASHTO M320
Softening Point °C	ASTM D36 & AASHTO T53	67	Min. 65°C
Rotational Viscometer at 135 °C, pa.s	ASTM D4402 & AASHTO T316	2122	Max. 3000 CP, AASHTO M320

RESULTS AND DISCUSSION

4.1 Mixing ratio of the proposed asphalt surface layer

Based on the results of laboratory tests of the raw materials shown earlier and pilot asphalt mixtures, the optimum mixing ratios for the raw materials and the

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optimum mixing equation for the surface layer were determined, as shown in Table 3. This design accounts for resistance to harsh climatic conditions and heavy traffic loads while maintaining the excellent mechanical properties of the asphalt surface layer.

Table 3 shows the exact mixing ratios for the materials used, including 18% medium-sized gravel (9.5-19 mm) to contribute to deformation resistance, 25% fine gravel (5-9.5 mm) to fill voids and improve granular gradation, and 55% crushed sand (0-5 mm) to increase density and crack resistance. Natural sand was excluded to maintain mixture stability, with 2% cement added to improve cohesion and reduce voids.

These proportions were achieved through a series of rigorous tests that ensured an optimal balance between the mixture's durability, flexibility, and resistance to cracking, while maintaining thermal stability and delivering outstanding performance under harsh operating conditions.

Table 3. Aggregate and filler mixing ratios

Material	Laboratory number	Source	Mixing ratios %	Role in the mixture
Medium crushed stone size (9.5-19) mm	1442	Brija Quarries	18	Resistance to rutting
Fine crushed stone size (5-9.5) mm	1443	Brija Quarries	25	Fill gaps and improve granularity
Crusher sand (0-5) mm/stone crushing output	1444	Brija Quarries	55	Increased density and crack resistance
Natural sand (0-5) mm	1445	Al-Kifl Quarries	0	Not used (to avoid inconsistency)
Cement	1446	Najaf/Kufa	2	Improve cohesion and reduce gaps

4.2 Properties of the proposed asphalt surface layer mixture

Aggregate properties

The surface layer mixing formula was developed based on the results of laboratory tests, as detailed in Table 4. The oversize aggregate stuck on the sieve

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3/4" shown earlier in Table was removed as it is outside the standard limit. It is clear from Table 4 The sieve analysis results demonstrated compliance with all required technical standards and specifications according to the 2003 Roads and Bridges Specifications and its amendments.

Table 4. Sieve analysis results of the asphalt surface layer

Test	Aggregate used in the final design	Equivalence Limits	Requirements under the 2003 Road and Bridge Specifications and Amendments for the Surface Layer
Percentage passing the 3/4-inch sieve	100	100	100
Percentage passing the 1/2-inch sieve	91	90-97	90-100
Percentage passing the 3/8-inch sieve	78	76-84	76-90
#4	54	48-60	44-74
#8	36	31-39	28-58
#50	14	9 -17	5 -21
#200	6.8	4.8-8.8	4 -10

Bitumen test results

Experimental programs were conducted to investigate the viscoelastic properties of the SBS polymer-modified bitumen. These tests are examined in order to make sure that modified bitumen with 4.2% SBS polymer by bitumen weight meets the PG76-10 specification. These tests involved rutting parameter, fatigue parameter, mass change, elastic recovery, and creep stiffness. The dynamic shear rheometer (DSR) was used to measure the rutting parameter ($G^*/\sin\delta$) for modified bitumen and modified bitumen after the Rolling Thin Film Oven Test (RTFOT). In this test, a 25mm polymer-modified bitumen sample with 1mm thickness sandwiched between two parallel plates is subjected to a sinusoidal strain with 10 rad/s frequency at 76°C. The test results showed compliance with PG76-10 specification, which indicates a significant improvement in rutting resistance of the SBS polymer-modified bitumen. Polymer-modified bitumen storage stability has been examined. The results showed that the storage stability of polymer-modified bitumen was within the PG76-10 specification, as shown in Table 5.

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Elastic recovery after RTFOT of the SBS polymer modified bitumen at 25°C is investigated, and the result showed that the elastic recovery of the SBS polymer modified bitumen was slightly higher than the minimum requirement of the PG76-10 specification. This influence is mainly due to molecules of SBS polymer forming three-dimensional networks, resulting in an increase in the strength and elasticity of the SBS polymer modified bitumen (Airey, G.D., 2004). Fatigue parameter ($G^* \cdot \sin \delta$) and creep stiffness of aged modified bitumen using Pressure Aging Vessel (PAV) were examined and compared to the PG 76-10 specification, as shown in Table 5.

The results demonstrated that SBS polymer-modified bitumen was within the PG76-10 specifications. This indicated that the SBS polymer-modified bitumen could resist harsh environmental conditions such as low temperature and fatigue cracks.

Table 5. SBS Polymer modified bitumen test results

Property	Test Standard	Result	Requirement (AASHTO M320)
SBS modified bitumen			
Dynamic shear, $G^*/\sin \delta @ 10 \text{ rad/s}$, 25mm plate: 1mm gap at 76°C, kPa	AASHTO T315	2.34	Min. 1.0 kPa
Storage stability, separation tendency difference between softening point, °C	ASTM D7173	1.20	Max. 4°C
SBS modified bitumen after RTFOT (AASHTO T240)			
Mass change after RTFOT	AASHTO T240	0.51	Max. 1%
Dynamic shear, $G^*/\sin \delta @ 10 \text{ rad/s}$, 25mm plate: 1mm gap at 76°C, kPa	AASHTO T315	4.98	Min. 2.2 kPa
Elastic Recovery, 25°C 10cm elongation, after RTFOT	AASHTO T301	77	Min. 75%
SBS modified bitumen after RTFOT and PAV at 110°C (AASHTO R28)			
Dynamic shear, $G^* \cdot \sin \delta$, 8mm plate: 2mm gap at 37°C, kPa	AASHTO T315	1472	Max. 6000 kPa
Stiffness Bending Beam S value Rheometer, Creep at 0°C, 60s M value	AASHTO T313	50	Max. 300 mPa
	AASHTO T313	0.45	Min. 0.300

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Asphalt mixture test results

The final distribution of the aggregate used in the polymer-modified asphalt surface layer is shown in Fig. 1. It illustrates the size distribution of fine and coarse aggregates in the mixture according to

SORB/R9 – 2003 GRADATION. This distribution ensures that the aggregates comply with the required grading limits and standard specifications. AASHTO M320 has also been adopted alongside the Iraqi specification to ensure the highest quality standards are achieved. The Iraqi General Specifications for Roads and Bridges and their amendments of 2003 were adopted, applying the requirements for polymer-enhanced asphalt (SBS) according to Chapter 3504/NEW-JOB MIX FORMULA.

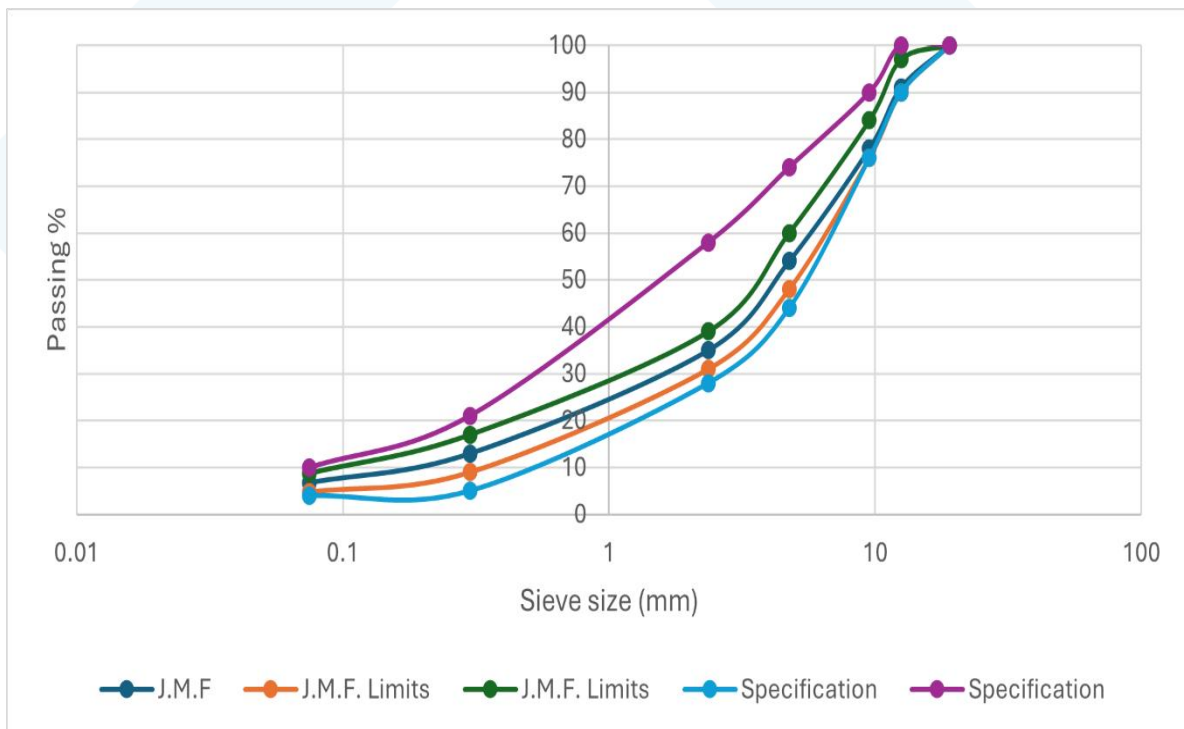


Fig. 1. Aggregate distributions throughout versus screen size (SORB/R9 – 2003 GRADATION)

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Marshall samples were prepared using 75 strokes per face, achieving a minimum of 95% coverage and sloughing test requirements. Test results using a 1:2 petroleum solvent and gasoline showed that the asphalt absorption and loss rate was only 0.2%. It was emphasized that the mixing equation should be re-evaluated when changing any of the raw materials. To ensure the quality of the asphalt mixture, accurate calibration devices were used, including laboratory-approved balances and scales. Analytical curves were used to illustrate the relationship between the asphalt percentage and the various mixture properties, including apparent density, strength, mineral void ratio, asphalt-filled void ratio, and fluidity measurement, to determine the optimum asphalt percentage according to standard criteria, as shown in Fig. 2. The results in Fig. 2 demonstrate that the mixture meets the basic requirements, with a bitumen content of 4.90% within the required range (4 - 6%). The mechanical performance characteristics demonstrated clear excellence, with a Marshall strength of 19.8 kN, almost twice the minimum required value (10 kN), and a creep of 4 mm within the optimum range (2-5 mm). The mixture also achieves a density of 2.36 g/cm³ with 4.40% air voids within the ideal range (3-5%), 15.50% mineral aggregate voids (within the required 14-16%), and a bitumen-filled void percentage of 72.00% (within the ideal 65-75%). The durability coefficient 83.00% exceeds the minimum required value (80%). At the same time, the filler-to-bitumen ratio achieved 1.39 within the optimum range of (0.8-1.5), confirming the quality of the design and its suitability for use as a surface layer under various operating conditions.

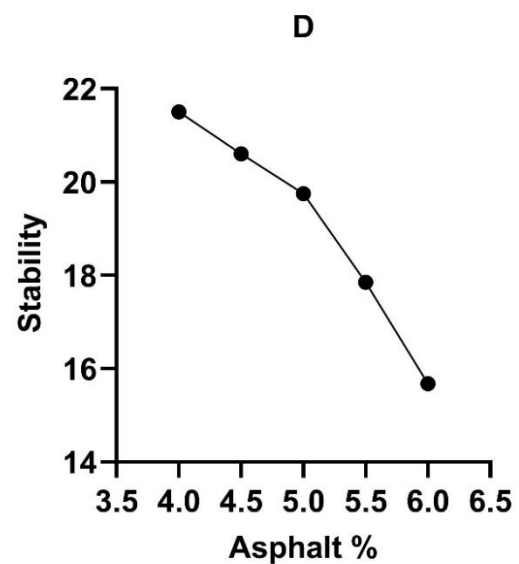
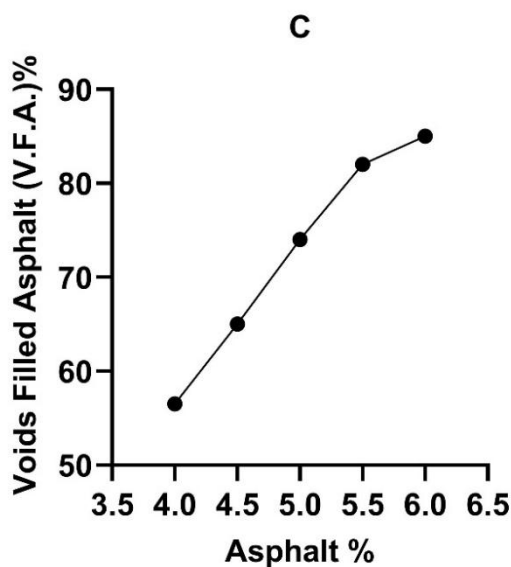
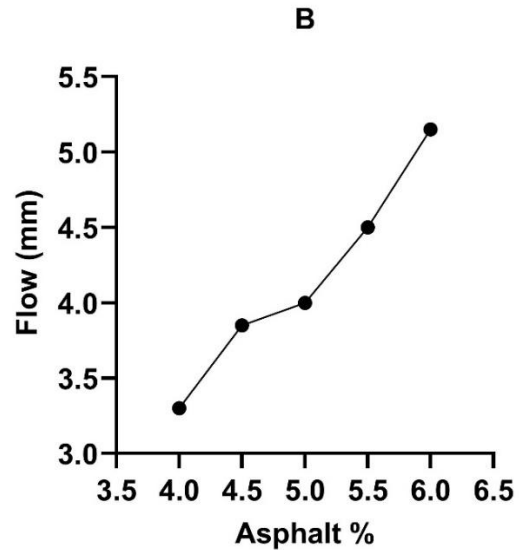
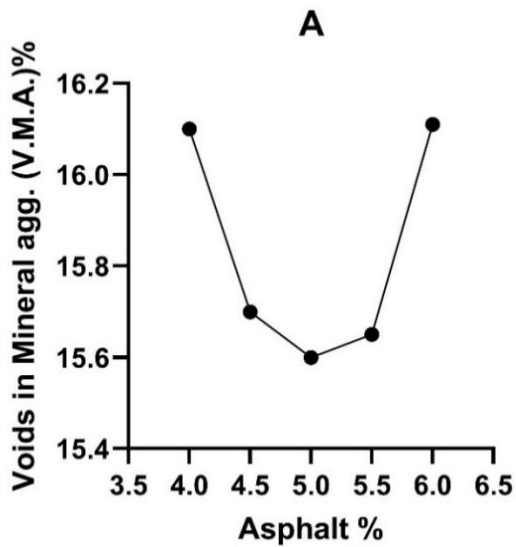
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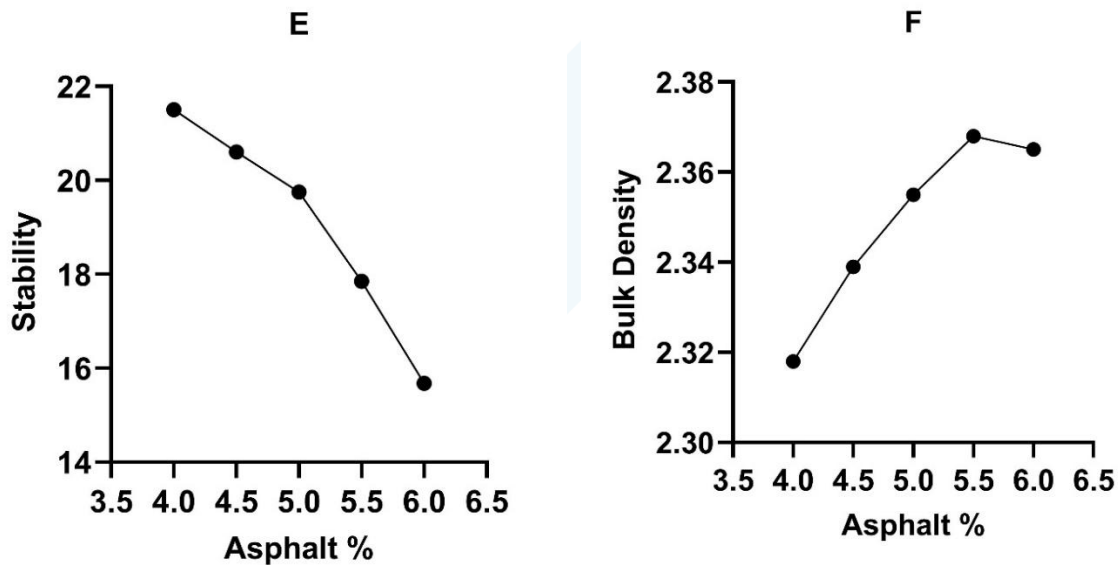


Fig. 2. Effect of bitumen content on asphalt mixture properties (VMA, Flow, VFA, Stability, and Density)

In summary, the designed polymer-modified asphalt surface layer demonstrated excellent properties that can stand harsh environmental and loading conditions, as shown in Table 6.

Table 6. SBS polymer-modified asphalt surface layer mixture properties

Property	Test results	Requirements under the 2003 Road and Bridge Specifications and Amendments for the Surface Layer
Asphalt percentage %	4.90	4 -6
Stability kN	19.80	10 min
Creep mm	4.00	2 -5
Marshall Density (g/cm)	2.36	
Air Voids %	4.40	3 -5
Voids in Mineral Aggregate %	15.50	14-16
Voids Filled with Asphalt %	72.00	65-75
Residual Strength Modulus %	83.00	80 min
Filler: Asphalt %	1.39	0.8-1.5

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CONCLUSIONS

Based on the analytical evaluation of the SBS polymer-modified asphalt surface layer and laboratory analysis, the following conclusions can be drawn:

When the 4.2% SBS polymer was incorporated into the base bitumen, according to AASHTO M320 specifications and a performance rating of PG76-10, the results showed a clear improvement in stress resistance, elastic recovery, and rutting resistance compared to conventional bitumen. This is what is required to withstand harsh climatic conditions. Furthermore, the results of the dynamic shear (DSR), RTFOT, and PAV tests indicate increased stiffness at high temperatures, sufficient impact resistance, and a 77% elastic recovery value, exceeding the minimum required. It is also worth noting that the Marshall properties were excellent, with an air void ratio of 4.4% and VMA and VFA values conforming to specifications. Therefore, this modified surface treatment is suitable for harsh climatic conditions and high temperatures. It should be noted that using SBS-modified bitumen significantly increases operating costs, but in return, it provides a longer service life in harsh climatic conditions, reducing periodic maintenance and thus benefiting long-term investments.

It is recommended to adopt this modified surface treatment mix under similar conditions, provided that periodic evaluation is conducted in case of any changes to the raw materials.

Author Contributions

Ghufran Ahmed Jawad Al-Baaj¹:

Conceptualization, methodology development, investigation, laboratory work on aggregate characterization and asphalt mixture preparation, data collection, and writing—original draft preparation.

Husam Abujwaid² (Corresponding Author):*

Conceptualization, supervision, project administration, experimental design of SBS polymer-modified asphalt, validation of laboratory results, rheological

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analysis (DSR, RTFOT, PAV interpretation), manuscript review and editing, and final approval of the submitted version.

Monketh Mohammed³:

Methodology support, experimental assistance, data analysis, Marshall mix design evaluation, result interpretation, and manuscript review and editing.

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