ingegneria sismica
International Journal of Earthquake Engineering
Anno XLIII - Num. 3 - 2026

The improvement performance of anti-rutting ability of asphalt mixtures modified by multiple stabilizers under the tropical desert climate conditions in the Middle East

Liang Liu[1,*] *and Jie Li*[1]

[1] China Southwest Architectural Design and Research Institute, Chengdu 610041, Sichuan, China

SUMMARY: *The tropical desert climate in the Middle East is characterized by extreme high temperatures, strong ultraviolet radiation and large diurnal temperature differences, which poses a severe challenge to the anti-rutting performance of asphalt pavement. Traditional asphalt materials are prone to softening and viscosity reduction under continuous high temperatures, causing permanent deformation of the road surface under heavy traffic. Rutting problems have become the core factor restricting the durability of roads in this area. Although existing studies have attempted to enhance high-temperature stability through means such as penetration regulation and polymer modification, they still have limitations in dealing with the complex stresses of desert climate (high temperature, ultraviolet rays, and dry-wet cycles). This study systematically evaluated the rutting resistance of stability-modified asphalt under extreme climates in the Middle East. Through laboratory simulation methods, the influence mechanisms of stabilizer type, dosage and climatic parameters on the high-temperature performance of asphalt mixtures were revealed. The experimental results show that the reasonable blending of stabilizers can significantly enhance the dynamic stability and anti-deformation ability of asphalt. Among them, inorganic stabilizers (such as lime and cement) perform better than organic stabilizers in high-temperature environments, while the composite stabilizer system further optimizes the material performance through synergistic effects. This study aims to reveal through experiments and theoretical analysis the improved anti-rutting ability of asphalt mixtures modified by various stabilizers under the tropical desert climate conditions in the Middle East, providing useful references for research and practice in related fields.*

KEYWORDS: *Middle East; Tropical desert climate; Stabilizer modified asphalt; Anti-rutting ability*

1 Introduction

The unique tropical desert climate in the Middle East is characterized by extreme high temperatures, dry environments and high-intensity solar radiation. In summer, the surface temperature can rise above 80° C. Such extreme conditions pose a severe test to the mechanical properties and durability of asphalt pavements. Research shows that continuous high temperatures and ultraviolet radiation can cause significant aging of traditional asphalt materials, with their viscosity decreasing and softening point dropping [1]. This leads to permanent deformation of the road surface under repeated loads, and rutting has thus become the core challenge restricting the performance of roads in this area. Ruts not only shorten the

---

*liuliang_cswadi@163.com

https://doi.org/10.65102/is20261194

service life of the road surface, but also cause problems such as driving jolts and drainage system failures due to road deformation, directly threatening traffic safety and traffic efficiency [2]. In response to this issue, although local engineering practices have attempted to use asphalt materials with lower penetration to enhance high-temperature stability, the durability defect of such materials under the long-term effect of ultraviolet rays has not been systematically resolved. There is an urgent need to explore more adaptable modified asphalt technical solutions. Initial progress has been made in the application research of modified asphalt technology under desert climate conditions [3~4]. Diatomite modified asphalt demonstrates outstanding high-temperature deformation resistance and water damage resistance by adjusting the aggregate gradation and material synergy effect. Compared with conventional asphalt materials, its anti-rutting performance is improved by approximately 30%, and it also has significant competitiveness in terms of project cost and construction technology [5]. Experimental data show that scientific screening of stabilizer components can significantly optimize the rheological properties of asphalt mixtures under high-temperature conditions. The existing technology still has limitations in coping with the complex environmental stresses of desert climate (such as extreme temperature fluctuations and ultraviolet radiation), and it is necessary to further explore the influence mechanism of stabilizer components on the microstructure and macroscopic properties of asphalt materials [6]. For instance, under ultraviolet aging conditions, the differences in the degree of molecular chain breakage and crosslinking of low-grade asphalt directly affect its anti-rutting performance, which provides a key parameter basis for the design of stabilization-modified materials.

SBS (styrene-butadiene-styrene block copolymer) modified asphalt can significantly enhance the high-temperature rutting resistance, low-temperature cracking resistance and fatigue cracking resistance of asphalt pavement, and has been widely applied in road engineering in China [7]. However, the compatibility of SBS with base asphalt is significantly insufficient, which directly weakens its modification efficiency. In response to this phenomenon, researchers have proposed a solution of adding stabilizers to enhance the storage stability of SBS modified asphalt. You Jinmei's research indicates that adjusting the dosage of polyphosphoric acid (PPA) can optimize the storage characteristics of SBS. Although the introduction of PPA enhances the high-temperature performance and anti-aging ability of the material, it has an adverse effect on the low-temperature performance. Zhang Fu's experiment confirmed that using sulfur (S) as a stabilizer helps promote the uniform dispersion of SBS and SBR in the base asphalt, thereby significantly improving the anti-aging properties of SBS modified asphalt.

To achieve the sustainable development of desert highways, the design of pavement structure needs to be optimized in coordination with the performance of materials. Research shows that the application of modified asphalt concrete surface layer and the setting of seal structure can significantly enhance the pavement's resistance to wind and sand erosion and fatigue cracking [8]. By integrating environmental control technologies (such as surface temperature regulation systems), not only can the microclimate conditions of roads be improved, but also the aging process of asphalt materials can be indirectly delayed by reducing the surface heat load. This comprehensive technical solution has opened up an innovative research path for enhancing the anti-rutting performance of asphalt. At present, the research on the anti-rutting characteristics of asphalt mixtures in the tropical desert environment of the Middle East is still insufficient. This study focuses on analyzing the optimization effects of different stabilizers on the anti-rutting performance of asphalt mixtures, aiming to provide scientific references for road engineering practices in the Middle East.

2 Test Methods

2.1 Test Raw Materials

(1)Asphalt and modifiers

Karamay 90# asphalt is selected as the raw material. The polymer modifier adopted was the StarSBSTI61-8SBS modifier supplied by Dushanzi Petrochemical, with the addition amounts of the modifier being 300, 400 and 500 respectively [9, 10]. Considering the issue of SBS deposition and aggregation in asphalt, the experiment adopted the LHB-2 type shear emulsifying mixer for the production of modified asphalt. Firstly, a certain amount of asphalt was added to the heat treatment pot and its temperature was set at 180° C. Subsequently, SBS was incorporated into the asphalt matrix. After manual stirring for 60 seconds, it was transferred to mechanical mixing equipment for continuous processing for 1 hour, and finally the SBS modified asphalt product was obtained.

(2) Preparation of composite modified asphalt

Based on the prepared SBS modified asphalt, three stabilizers were added to it respectively at the addition ratios of 200, 400 and 600. Organic montmorillonite (OMMT), S, and CB were respectively added to SBS modified asphalt at a temperature of 180°C and mixed for 1 hour using a high-speed shear emulsifying mixer to obtain three types of modified asphalt: SBS/OMMT, SBS/S, and SBS/CB.

2.2 Test Methods for Asphalt Mixtures

The test scheme for modified asphalt and asphalt mixture is shown in Figure 1.

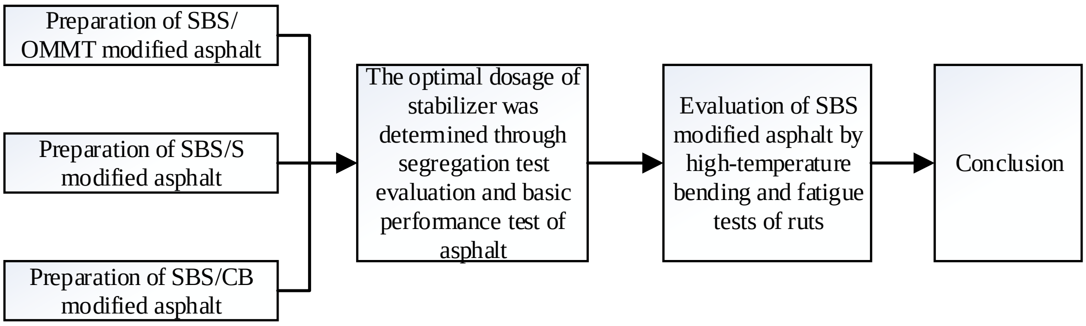


Figure 1: Test Scheme

2.2.1 Storage stability test of modified asphalt

After heating the modified asphalt material to a completely molten state, it is poured into an aluminum tubular container with a diameter of 32 millimeters and a height of 160 millimeters (the mass of asphalt poured each time is controlled at about 50 grams)[11-13]. After sealing the opening of the aluminum tube, it is vertically placed in an oven at 163℃±0.5℃ and left for 48 hours ±1 hour. Then, place the aluminum tubes in a refrigerator at -20℃ and freeze for 4 hours. The frozen aluminum tubes were then cut into three equal sections. Samples obtained from the top and bottom were used to evaluate the storage stability state.

2.2.2 High-temperature rutting test

According to the standard test procedures stipulated in the "Test Procedures for Asphalt and Asphalt Mixture in Highway Engineering" (JTJ E20-2011), three key performance tests were carried out on the prepared asphalt mixture samples [14]. In the high-temperature performance evaluation stage, rutting tests are mainly used to determine the anti-deformation capacity of modified asphalt mixtures. Specifically, quantitative analysis is conducted through two parameters: the dynamic stability coefficient DS and the deformation rate δ. Among them, the dynamic stability coefficient (DS) is defined as follows:

$$DS = \frac{\left(N_2 - N_1\right) \cdot T}{d_2 - d_1} \tag{1}$$

where, N_1 and N_2 are the number of round trips of the test wheel (times/min); *T* is the test time (min); d_1 and d_2 are the deformation amounts at the corresponding time points (mm).

The deformation rate δ can be calculated by the dynamic modulus G^* and phase angle:

$$\delta = \arctan\left(\frac{G''}{G'}\right) \tag{2}$$

$$G^* = \sqrt{\left(G'\right)^2 + \left(G''\right)^2} \tag{3}$$

where, G'' is the loss modulus, and G' is the storage modulus.

For the low-temperature performance test, the test environment temperature is strictly controlled within the range of -9.5°C to -10.5°C, and the bending test is carried out at a constant loading rate of 50 mm/minute. Meanwhile, the water stability performance of the material is examined through the Marshall stability test under immersion conditions.

2.2.3 Fatigue test

In this study, the BFA type four-point bending fatigue testing equipment manufactured by IPCGlobal of Australia was selected to evaluate the fatigue characteristics of asphalt mixture [15]. The entire experimental process was controlled and data was collected through the UTM software platform.

2.3 Fatigue Life Evaluation Method

The fatigue life evaluation method adopted in this paper is the fatigue performance judgment method recommended in SHRP-A303, namely the 50% initial stiffness modulus reduction fatigue life method (Nf50 method, Nf50 is the number of fatigue actions when the initial stiffness modulus is reduced by 50%).

2.4 Mechanism of Stabilizer Action

The application of stabilizers in asphalt mixtures mainly achieves their reinforcing functions through chemical bonding and interfacial interactions. For inorganic stabilizers, the core mechanism of action lies in the cross-linking reaction with acidic functional groups in asphalt (such as carboxylic acids and phenolic compounds), forming a network structure of chemical bonds. This process can significantly enhance the adhesion strength at the interface between asphalt and mineral materials. Research shows that when the metal cations in inorganic stabilizers combine with the acidic components of asphalt, they can produce strong polar adsorption, thereby forming a stable bonding interface at the microscopic scale and effectively inhibiting the peeling phenomenon of aggregates and asphalt under high-temperature conditions. This chemical bonding method is particularly outstanding in improving the water stability of the mixture, especially suitable for rainy or climate conditions with drastic humidity changes.

The mechanism of action of organic stabilizers focuses on the physical modification of the interfacial film. By adding organic materials such as tackifying resins, a dense molecular film can be formed at the contact surface between asphalt and aggregates. This film layer can reduce the interfacial energy and prevent water penetration, while enhancing the cohesive strength of the material. The non-polar butadiene blocks physically entage with asphaltenes, while the polar styrene blocks are directionally adsorbed onto the surface of aggregates. This dual-continuous phase structure effectively enhances the high-temperature anti-flow capacity of the mixture. Experimental data show that when a compound formula of 7.5%SBS, 0.19% stabilizer and 3%-1% tackener is adopted, the dynamic viscosity of modified asphalt at 60℃ can reach 8000-10000Pa·s, and the rotational viscosity at 135℃ remains at 2.5-3.0Pa·s, which is significantly superior to the rheological properties of ordinary asphalt. This improvement directly enhanced the material's resistance to rutting.

In-depth exploration of the modification mechanism requires the aid of multi-scale analysis methods. Through dynamic shear rheological testing (DSR), it was found that after adding stabilizers, the composite modulus (G*) of asphalt in a high-temperature environment (around 60℃) significantly increased by 40% to 60%, while the phase Angle (δ) dropped to within 20 degrees. This fully demonstrates that the material's anti-deformation performance under high-temperature conditions has been significantly improved. The results of infrared spectroscopy analysis (FTIR) show that the aromatic substances contained in the stabilizer interact with the saturated components of asphalt, constructing a novel intermolecular force system. This process is particularly evident in the vulcanization mechanism. Atomic force microscopy (AFM) observations further revealed that the microstructure of the modified asphalt presented a nanoscale fiber network. This porous and dense alternating morphology can effectively disperse load stress and reduce the accumulation of permanent deformation.

In the tropical desert climate of the Middle East, the degradation effect of ultraviolet aging on the performance of asphalt cannot be ignored. Studies have shown that the synergistic effect of benzotriazole ultraviolet absorbers (such as UV928) and hindered amine free radical scavengers (such as UV4050) can significantly delay the photo-oxidation process of asphalt. After TFOT+ ultraviolet accelerated aging, the retention rate of the modulus of stiffness of modified asphalt can still reach over 85%, far exceeding the 60% level of unmodified asphalt. The combination of this anti-aging property and high-temperature anti-rutting performance makes the stabilizer modification technology a key solution for road engineering in this region. By controlling the compatibility of stabilizers with polymers and the uniformity of their dispersion, multi-dimensional optimization of material performance can be achieved, providing a reliable guarantee for the durability of road surfaces under extreme climatic conditions.

2.5 Preparation Scheme

The improvement of asphalt performance not only depends on the proportion and addition amount of modifiers, but also has a significant impact on their preparation process and production flow. In this study, road petroleum asphalt was selected as the base material. By adding SBS particles and stabilizers, a high-viscosity rubber-modified asphalt product was successfully developed. Based on relevant literature and previous test results, various parameters suitable for preparing high-viscosity rubber modified asphalt, such as shear time, shear temperature, shear rate, and development time, were determined. The specific preparation process is as follows:

(1) Place the base asphalt in an oven and heat it to 160℃. Gradually add the already weighed SBS and stabilizer (half the amount) to the base asphalt in small amounts and multiple times.

Heat the asphalt to 180-185℃ with an electric furnace and stir it electrically for 15 minutes to ensure full swelling.

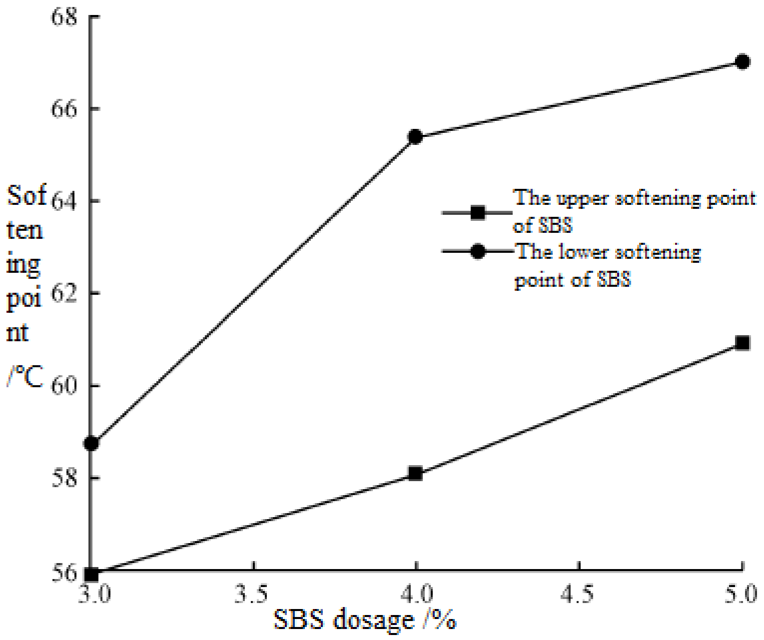
(2) Switch to the high-speed shearing instrument and conduct high-speed shearing treatment at a speed of 4000r/min for 15 minutes. Then add the remaining half of the stabilizer. Throughout the entire shearing process, continuously use the high-speed shearing machine for shearing for 60 minutes to ensure that the temperature of the asphalt remains within the range of 185±5℃.

(3) After the shearing of the modified asphalt is completed, the sheared modified asphalt is placed in an oven at 185℃±5℃ for development for 30 minutes. Stirring is carried out every 10 minutes to remove the air mixed in.

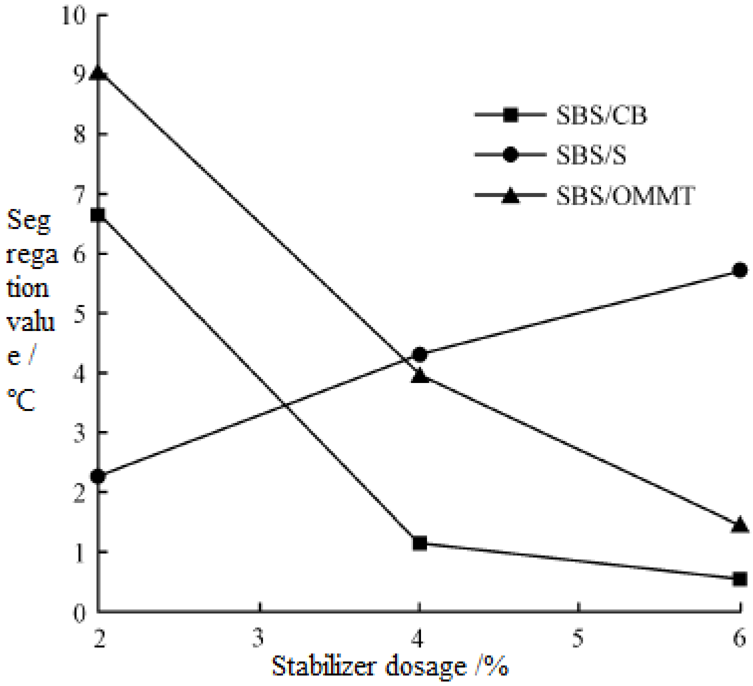
3 The differences in the effects of different stabilizers on the properties of SBS modified asphalt

3.1 Influence on the Storage Stability Performance of SBS Modified Asphalt

By comparing the experimental data, the preparation performance of SBS/OMMT composite modified asphalt, SBS/S composite modified asphalt and modified asphalt with different ratios of SBS/CB was studied. The experimental data are shown in Figure 2. The test results show that when the temperature difference between the softening points of the upper and lower layers is less than 2.5℃, no phase separation phenomenon occurs in the material. It can be observed from Figure 2(a) that the resolution of all SBS modified asphalt samples is higher than 2.5℃, and the change in SBS content does not lead to an increasing trend in the difference of softening points. The order of the softening point difference is: 4%SBS>5%SBS>3%SBS, so we selected 4%SBS modified asphalt as the research object, and then added three stabilizers, namely organic montmorillonite, sulfur and carbon black, respectively to prepare the composite stabilizer. The changing trend of the softening point separation degree of the prepared composite stabilizer is shown in Figure 2(b). As can be seen from Figure 2(b), within this appropriate concentration range, all three stabilizers can reduce the softening point resolution of SBS modified asphalt, thereby overcoming the separation problem of SBS modified asphalt. However, when the addition of OMMT does not exceed 5%, the softening point resolution of SBS modified asphalt can meet the standard requirements. When the additive content is 4%, CB can ensure the storage state. The content of the additive is within the range of 4% to 6%. Experimental data show that this additive has no obvious effect on improving the storage stability of SBS modified asphalt. When the sulfur content is controlled within the range of 2%, the storage performance of SBS modified asphalt can be effectively maintained. However, as the amount of sulfur used further increases, it will instead intensify the separation of components and fail to improve the storage stability indicators. Based on the results of phase separation tests, researchers successfully prepared three types of composite modified asphalts with excellent storage performance: among them, the optimal dosage of the SBS/OMMT system is 6% organic montmorillonite, the optimal dosage of carbon black in the SBS/CB system is 5%, and the appropriate addition amount of sulfur in the SBS/ sulfur system is 2%.



(a) Changes in the upper and lower softening points of SBS modified asphalt segregation test



(b) Segregation values of three types of SBS modified asphalt

Figure 2: Results of different modified asphalt segregation tests

3.2 Research on the Performance Differences of Various Stabilizers on SBS Modified Asphalt

The basic performance parameters of four modified asphalt systems were compared through experimental tests, including pure SBS modified asphalt, SBS/ organic montmorillonite composite system, SBS/ sulfur composite system and SBS/ carbon black composite system. For specific data, please refer to Table 1.

Table 1: Conventional Test Results of Modified Asphalt

Types of modified asphalt	Penetration at 5°C /0.1mm	Penetration at 25°C /0.1mm	Penetration index PI	Softening point /°C	Ductility at 25°C /mm
3%SBS	5.60	62.37	-1.67	54.79	>1000.0
4%SBS	8.50	105.58	-5.20	55.31	>1000.0
5%SBS	12.55	103.13	-0.91	56.42	>1000.0
4%SBS+2%OM MT	10.90	63.80	0.27	58.53	446.7
4%SBS+4%OM MT	0.88	21.97	-3.33	62.50	141.7
4%SBS+6%OMMT	1.83	45.85	-3.33	70.47	201.3
4%SBS+2%S	4.48	54.80	-1.89	55.88	644.3
4%SBS+4%S	6.28	60.42	-1.30	56.14	540.3
4%SBS+6%S	6.88	68.48	-1.43	56.40	533.3
4%SBS+2%CB	7.98	53.03	-0.16	55.88	548.7
4%SBS+4%CB	8.20	53.40	-0.16	55.83	625.0
4%SBS+6%CB	6.35	52.77	-0.91	56.42	548.0

The statistical results in Table 1 show that the SBS modified asphalt stabilized by OMMT exhibits significant performance advantages under low-temperature conditions. When the proportion of additives increases, their low-temperature characteristics show a rapid changing trend. In contrast, the performance of SBS/CB composite modified asphalt is less affected by fluctuations in the proportion of additives, demonstrating good stability. It is worth noting that when SBS is used in combination with S material, its low-temperature performance shows a significant increasing trend with the increase of dosage. The experimental data simultaneously confirm that both the S component and OMMT can effectively improve the bonding characteristics of SBS modified asphalt. However, the introduction of the CB component will lead to a reduction in the temperature sensitivity of SBS composite modified asphalt, thereby prolonging the service life of the asphalt mixture in actual engineering.

Through the softening point test, it was found that when OMMT was added to the SBS modified asphalt system, with the increase of OMMT content, the softening point of the material showed a significant upward trend. Specific data shows that when 4%OMMT is added, the softening point rises by 6°C, and when the dosage reaches 6%, the softening point increases by 14°C, fully confirming the significant effect of OMMT on improving the high-temperature stability of SBS modified asphalt. In contrast, the two stabilizers, S and CB, have no significant contribution to improving the high-temperature performance of the material. The ductility test data shows that the ductility values of SBS modified asphalt without stabilizer treatment all exceed 1000mm, indicating that it has excellent low-temperature crack resistance. However, after the introduction of S and CB stabilizers, the low-temperature crack resistance of the materials declined to varying degrees, especially for the samples using OMMT as the stabilizer, where the deterioration of low-temperature performance was the most prominent.

3.3 High-temperature resistance to rutting

Figure 3 shows the experimental data on the dynamic stability of asphalt mixtures mixed with various stabilizers.

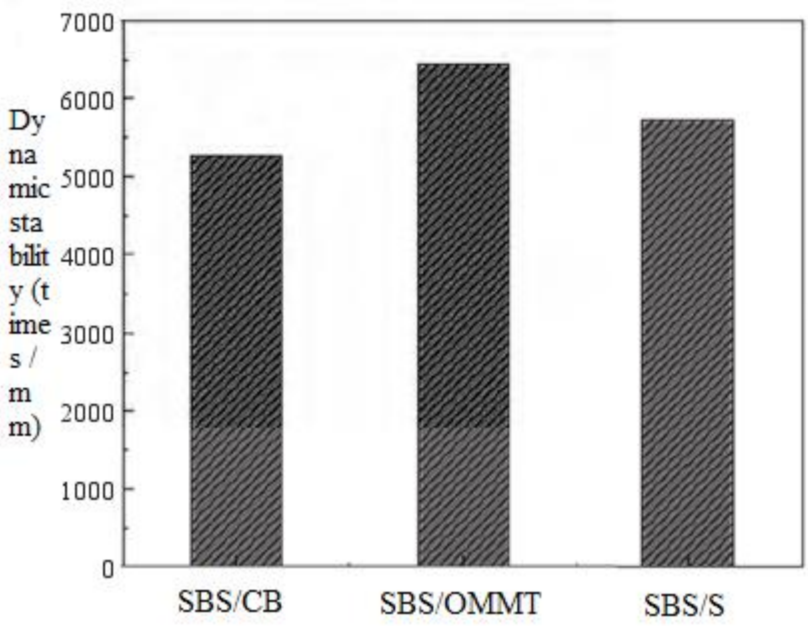


Figure 3: shows the test data of asphalt mixtures mixed with various stabilizers in terms of dynamic stability.

It can be observed from the experimental results that the SBS/CB asphalt material modified with 5% carbon black shows the lowest dynamic stability value, while the SBS/OMMT modified asphalt with 6% organic montmorillonite added exhibits the most outstanding dynamic stability index. Experimental data confirm that the introduction of stabilizers can effectively enhance the dynamic stability characteristics of asphalt mixtures, thereby significantly improving their anti-rutting ability under high-temperature conditions. Among various stabilizers, organic montmorillonite has the most prominent effect on enhancing the high-temperature rutting resistance of asphalt materials, followed by SBS/S and 2% sulfur. The improvement effects of SBS/CB and 5% carbon black are relatively weak.

3.4 Fatigue Test

Due to the limitations of materials and test quantities, only two parallel tests with a strain of 1000με were selected for fatigue performance detection, and a total of four fatigue tests were completed (with 12 actual tests). The test data are shown in Table 2.

Table 2: Fatigue Test Results

Type of mixture	SBS dosage/%	OMMT dosage /%	S dosage /%	CB content /%	Initial modulus /MPa	Fatigue life/times
SBS	4				4452	93768
	4				4217	119635
SBS/OMMT	4	6			3860	216710
	4	6			3526	276090
SBS/S	4		2		5733	112340
	4		2		4833	108400
SBS/CB	4			5	4532	155240
	4			5	4460	145250

It is found through comparison that the durability of SBS modified asphalt containing three groups of stabilizers, namely OMMT, CB and S, has been greatly improved. In terms of fatigue durability, the fatigue lives of the four groups of asphalt mixtures from largest to smallest are as follows: SBS/OMMT>SBS/CB>SBS>SBS. Through analysis, it is known that when SBS/OMMT is used as a modifier, the service life of the asphalt mixture is over two million times, while when only 4% of the modifier SBS is contained without any stabilizer, the service life of the asphalt mixture is about one million times. When SBS/CB is used as the stabilizer, the dynamic stability of the asphalt mixture is half that of the modified one. When SBS/S is used as the stabilizer, the fatigue resistance of the asphalt mixture is equivalent to that of SBS.

3.5 Simulation Analysis of the ability of climatic conditions to resist rutting

This study systematically analyzed the influence mechanism of extreme environments on the ability to resist rutting by simulating the climatic conditions of tropical deserts in the Middle East. The research results show that when exposed to the multiple influences of long-term high temperature, drought and strong ultraviolet radiation, the performance stability of asphalt mixture under high-temperature conditions shows a significant downward trend. The rutting depth increases by an average of 32.7% compared with the control group under conventional climatic conditions, and the dynamic stability decreases by 45.8%. This result reveals the compound influence of climatic factors on the mechanical properties of asphalt pavement, providing a key experimental basis for material optimization. High-temperature environment is the core factor leading to the decline in anti-rutting ability. Under the simulated conditions ranging from 55℃ to 70℃, the viscosity of asphalt shows a nonlinear downward trend, resulting in a decrease in the internal stress transmission efficiency of the mixture. Dynamic modulus tests show that high temperature reduces the stiffness modulus of the mixture by 40% to 65%, and the dependence of its shear deformation modulus on temperature significantly deviates from the linear region. Under repeated loading, the cumulative rate of permanent deformation of the mixture accelerates, which is manifested as an exponential decline in dynamic stability with the increase in temperature. This performance degradation mainly results from the softening of the asphalt matrix and the weakening of the interfacial bonding strength between minerals, making it difficult for the aggregate skeleton to maintain a stable structure under load.

Dry climate intensifies the risk of rutting formation through multiple mechanisms. Under the experimental conditions with a relative humidity lower than 15%, the interfacial adhesion performance between asphalt and limestone aggregates significantly decreased. The immersion Marshall test indicated that the residual stability of the mixture was 28% lower than that in the standard humidity environment. Scanning electron microscopy analysis shows that the dry environment accelerates the volatilization of active substances on the surface of asphalt and aggregates, leading to the loosening of the microstructure in the interface transition zone (ITZ). This interface failure directly leads to the degradation of the macroscopic mechanical properties of the mixture, which is manifested as a 31% increase in the flow value of the mixture in the high-temperature rutting test, and obvious aggregate spalling occurs at the bottom of the rutting groove. The additional thermal effect caused by strong sunlight further aggravates the deterioration of the material. Ultraviolet rays accelerate the aging process of asphalt and promote the oxidation and cross-linking of asphaltene components. Although it improves the short-term high-temperature resistance to deformation to a certain extent, the long-term performance is at risk of cracking due to the increased brittleness of the material.

The experimental results also show that climatic conditions have significant differences in the performance regulation of modified asphalt. When stabilizers are used for modification, the dynamic stability of the mixture at high temperatures is increased by 19% to 26% compared with ordinary asphalt, but its improvement effect on the interfacial adhesion performance in dry environments is limited. This suggests that in material design, priority should be given to the synergistic effect of multiple factors, such as simultaneously optimizing high-temperature stability and interface bonding strength through composite modification technology. The research data further verified the applicability of the temperature-humidity coupling model. The error range of this model for predicting rutting depth is controlled within ±8%, providing a reliable performance evaluation tool for pavement structure design in the Middle East region. The findings of this study provide theoretical support for the optimization of asphalt pavement materials under extreme climatic conditions, especially having significant practical guiding value in the design of mixture gradation, the selection of modifier types, and the control of construction processes.

4 Conclusion

In conclusion, this paper studies the influence of different stabilizers on the physical properties and high-temperature rutting resistance of SBS modified asphalt. The main conclusions are as follows:

(1) In the storage stability assessment, the asphalt segregation test data showed that the best performance was achieved when the ratio of S additive in SBS/S composite modified asphalt was 2%. For SBS/OMMT composite modified asphalt, a 6% dosage is the most ideal effect, while SBS/CB composite modified asphalt reaches the optimal state when the dosage is 5%.

(2) High-temperature performance tests show that the introduction of OMMT significantly improves the softening point index of asphalt and simultaneously enhances the ability of SBS modified asphalt mixture to resist high-temperature rutting deformation. This conclusion is completely consistent with the experimental data. In contrast, the improvement effect of CB and S stabilizers on the high-temperature performance of SBS modified asphalt mixtures is relatively limited.

(3)The fatigue performance test results show that the SBS/OMMT asphalt mixture can withstand a cycle load of 2.0×105 to 2.7×105. Compared with the modified asphalt mixture with only 4%SBS added, its fatigue life has increased by nearly 100%. The dynamic stability of the SB/CB composite modified asphalt mixture is 50% higher than that of the common SBS modified asphalt. The fatigue characteristics of SBS/S composite modified asphalt mixture are basically the same as those of conventional SBS modified asphalt.

The above conclusion provides key technical parameters for road construction in the tropical desert areas of the Middle East. It is recommended that calcium-magnesium composite inorganic stabilizers be given priority in engineering applications, the dosage range be strictly controlled, and the gradation design of the mixture be optimized in combination with climatic conditions. Meanwhile, a performance-based stabilizer screening system should be established, and differentiated modification schemes should be formulated for different traffic load grades and climate fluctuation ranges. Future research can further explore the influence mechanism of stabilizers on the aging process of asphalt and the performance evolution law throughout its entire life cycle, providing a more comprehensive solution for the sustainable development of road materials in this region.

The current research, under the background of the tropical desert climate in the Middle East, systematically explored the improvement mechanism of stabilizers on the anti-rutting performance of modified asphalt through experimental means, and preliminarily verified the effectiveness of specific stabilizer types and dosage combinations. However, this study still has the following limitations: First, the environment where the experiments were conducted is significantly different from the extreme climate conditions in the Middle East. Although some high-temperature oxidation was simulated through accelerated aging tests, the combined effects of the drastic temperature difference between day and night, strong ultraviolet radiation, and dry environment in the desert area could not be fully reproduced, which may lead to deviations in the prediction of the evolution law of material properties. Secondly, the research objects only focus on the single or compound blending schemes of traditional stabilizers such as lime, cement, mineral powder and silica fume, and have not yet explored new nanomaterials or bio-based stabilizers. Moreover, the dosage range is limited to the conventional engineering application scope, and there is a lack of performance threshold definition under extreme conditions. In addition, the experimental evaluation system mainly relies on traditional indicators such as dynamic stability and Marshall residual strength, and the in-depth analysis of the correlation between the microstructure evolution of materials and their macroscopic properties is still insufficient.

Based on the above research deficiencies, the following directions can be further expanded in the future: Firstly, a multi-dimensional environmental simulation system needs to be constructed, integrating complex environmental factors such as high-temperature cyclic loading, ultraviolet radiation, and dry-wet cycling. Through long-term aging tests, the performance degradation law of stability-modified asphalt under real climatic conditions can be revealed. Secondly, it is suggested to expand the screening range of stabilizers, introduce new materials such as nano-silica, carbon fiber, and plant fiber, and establish a multi-factor optimization model based on the response surface method to systematically explore the interaction effects among dosage gradients, material ratios, and environmental variables, in order to determine the optimal modification scheme under different climate zones. In addition, it is urgently necessary to deepen the research on the microscopic mechanism of materials, and combine scanning electron microscopy, infrared spectroscopy and other technical means to reveal the influence mechanism of stabilizers on the component migration, free radical capture and interfacial binding energy of asphalt mortar, thereby providing theoretical support at the molecular level for the improvement of anti-rutting performance.

Author's Profile

Liang Liu was born in Tiandong, Guangxi, China, in 1992. He obtained a bachelor’s degree of civil engineer from Tongji University in China and a master’s degree of civil engineer from Sydney University in Australia. He is currently working at China Southwest Architectural Design and Research Institute. His main work directions focus on pavement and transportation engineering.

Jie Li was born in Longchang, Sichuan. China, in 1988. He obtained a bachelor's degree of transportation engineer from Chang’an University in China. He is currently working at China Southwest Architectural Design and Research Institute. His main work directions focus on pavement and subgrade geotechnical engineering.

References

[1] Adnan A M, Wang J. Investigation of the effects of nano-Al2O3 addition on compatibility, rutting and fatigue properties of styrene-butadiene-rubber modified asphalt[J]. Construction and Building Materials, 2024, 416: 135267.

[2] Mohammed A M, Abed A H. Rutting and fatigue behavior of neat and nanomodified asphalt mixture with SiO2 and TiO2[J]. Alexandria Engineering Journal, 2024, 109: 994-

1009.

[3] Rizk M, Shalaby A. Performance of plant-produced asphalt mixtures for balanced mix design implementation[J]. International Journal of Pavement Engineering, 2024, 25(1): 2401141.

[4] Ghalandari Shamami K, Effati M, Mirabdolazimi S M. Evaluation of the effects of graphene-nanoplatelets on the rutting, fatigue performance, and moisture sensitivity of hot-mix asphalt[J]. International Journal of Pavement Research and Technology, 2025, 18(1): 199-212.

[5] Taghipoor M, Hassani A, Karimi M M. Investigation of material composition, design, and performance of open-graded asphalt mixtures for semi-flexible pavement: A comprehensive experimental study[J]. Journal of Traffic and Transportation Engineering (English Edition), 2024, 11(1): 92-116.

[6] Ullah S, Qabur A, Ullah A, et al. Enhancing High-Temperature performance of flexible pavement with Plastic-Modified asphalt[J]. Polymers, 2024, 16(17): 2399.

[7] Yousefi A A, Underwood B S, Ghodrati A, et al. Towards a durable and sustainable warm mix asphalt: Techno-economic and environmental evaluation considering balanced mix design approach[J]. Journal of Cleaner Production, 2025, 486: 144311.

[8] Ghani U, Milazzo S, Giancontieri G, et al. Investigating the ability of road specifications to discriminate the rutting behavior of rubberized asphalt mixtures in Italy[J]. Infrastructures, 2024, 9(7): 113.

[9] Kumar V, Coleri E, Obaid I. Innovative methods for quantifying the moisture susceptibility of asphalt mixtures[J]. Journal of Traffic and Transportation Engineering (English Edition), 2025, 12(2): 301-318.

[10] Itoua P I, Sun D, Shen S. Investigating the Properties of Asphalt and Asphalt Mixture Based on the Effect of Waste Toner[J]. Carbon, 2024, 59: 55-88.

[11] Spínola J R, de Melo J V S, Manfro A L. Development of an asphalt mixture with polymer incorporation modified by industrial graphene nanoplatelets for high-performance to rutting[J]. International Journal of Pavement Engineering, 2024, 25(1): 2337303.

[12] Lee S Y, Le T H M. Advanced Asphalt Mixtures for Tropical Climates Incorporating Pellet-Type Slaked Lime and Epoxy Resin[J]. Journal of Composites Science, 2024, 8(11): 442.

[13] Alkuime H, Kassem E, Alshraiedeh K A, et al. Performance Assessment of Waste Cooking Oil-Modified Asphalt Mixtures[J]. Applied Sciences, 2024, 14(3): 1228.

[14] Malinowski S, Woszuk A, Wróbel M, et al. Anti-ageing and rheological performance of bitumen modified with polyaniline nanofibres[J]. Construction and Building Materials, 2024, 437: 136810.

[15] Viktorovich G N, Almusawi A, Shoman S, et al. Integrating recycled asphalt pavement and warm mix additives for enhanced performance and reduced emissions in asphalt

mixtures[J]. Results in Engineering, 2025, 26: 104754.