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# Study on Performance Optimization and Maintenance Technology of Regenerant on Modified Asphalt Pavement

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## Abstract

**With the extensive network of high-grade highways in China entering a maintenance phase, the disposal of large quantities of Reclaimed Asphalt Pavement (RAP), particularly containing aged SBS-modified asphalt, has become a pressing issue. Addressing the performance degradation of aged SBS-modified asphalt, this study investigates the effectiveness of a composite rejuvenator in restoring and optimizing its properties. Through laboratory tests, including penetration, softening point, ductility, and Dynamic Shear Rheometer (DSR) tests on asphalt with varying rejuvenator content, the high-temperature, low-temperature, and fatigue performance of the rejuvenated asphalt were systematically evaluated. The results indicate that this composite rejuvenator effectively replenishes the light fractions of the aged asphalt and restores its rheological properties, with an optimal dosage identified at 6%. At this dosage, the high-temperature performance of the rejuvenated asphalt recovers to over 95% of that of virgin asphalt, while its low-temperature performance is significantly enhanced, and its fatigue life is increased by approximately 30%. This research provides important theoretical and data support for maintenance techniques applied to modified asphalt pavements incorporating RAP.**

## Keywords

**Rejuvenator; Asphalt Pavement; Maintenance Technology; Performance Optimization; SBS-modified Asphalt.**

## 1. Introduction

Asphalt pavements, recognized for their driving comfort and ease of maintenance, are predominantly used in China's highway network. Among them, SBS-modified asphalt is widely applied in surface layers of high-grade roads due to its excellent resistance to high-temperature rutting[1], low-temperature cracking[2], and fatigue[3-4]. However, during long-term service, asphalt pavements undergo aging under the combined effects of heat, oxygen, ultraviolet radiation, and traffic loads[5]. This leads to an increase in asphaltenes and a decrease in maltenes, causing the pavement to become brittle and hard, ultimately resulting in distress such as cracking[6] and raveling, thus entering the maintenance cycle.

The traditional milling-and-resurfacing maintenance method generates substantial amounts of Reclaimed Asphalt Pavement (RAP)[7]. Simply discarding this material not only occupies land and pollutes the environment but also constitutes a significant waste of resources. Consequently, aligned with the green maintenance philosophy of "resource conservation and environmental friendliness," asphalt pavement recycling technologies have become a key research and application focus. In central plant hot recycling, the primary role of a rejuvenator is to replenish the lost light oil fractions in the aged asphalt[8] and regulate its colloidal structure, thereby restoring or even enhancing its service performance[9].

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Currently, research on the recycling of conventional neat asphalt is relatively mature. However, the regeneration mechanism and performance optimization pathways for the complex structure of aged SBS-modified asphalt still require in-depth exploration. This study aims, through a series of laboratory tests, to investigate the effectiveness of a composite rejuvenator in restoring the key performance indicators of aged SBS-modified asphalt, determine its optimal dosage, and analyze its performance optimization mechanism, thereby providing a scientific basis for practical engineering applications.

## 2. Experimental Program

### 2.1 Materials

Aged SBS-Modified Asphalt: The aged SBS-modified asphalt was prepared through laboratory simulation of short-term aging. The virgin SBS-modified asphalt (grade I-D) was aged in a Rolling Thin Film Oven (RTFOT) at 163° C for 85 minutes to simulate the aging that occurs during mixing and paving. Its fundamental properties are summarized in Table 1.

Composite Rejuvenator: A commercially available composite rejuvenator was employed in this study. It is primarily composed of petroleum-based soft components, an active compatibilizer, and an anti-aging agent. The corresponding technical specifications are provided in Table 1.

Virgin Asphalt: For performance comparison, two types of virgin asphalt were used as benchmarks: 70# base asphalt and SBS-modified (I-D) asphalt.

**Table 1.** Basic properties of raw materials

| Inspection project | Unit | Original SBS | Aging SBS | Composite regenerant | Test method |
|---|---|---|---|---|---|
| Penetration（25℃） | 0.1mm | 65 | 38 | >200 | T0604 |
| Softening point | ℃ | 78 | 85 | 45 | T0606 |
| Ductility（5℃） | cm | 32 | 15 | - | T0605 |
| Viscosity（135℃） | Pa·s | 1.8 | 3.5 | 0.15 | T0625 |

### 2.2 Preparation of Rejuvenated Asphalt

The aged SBS-modified asphalt was heated in an oven at 140℃until it reached a fluid state. The composite rejuvenator was then added at dosages of 4%, 5%, 6%, and 7% by mass of the aged asphalt, respectively. Each mixture was homogenized using a high-speed shear mixer operating at 5,000 rpm for 20 minutes to ensure uniform dispersion of the rejuvenator within the aged asphalt, thus producing rejuvenated asphalt samples with varying rejuvenator contents.

### 2.3 Performance Test Methods

Conventional Performance Tests: Tests for penetration (25°C), softening point, and ductility (5°C) were conducted in accordance with the Chinese specification JTG E20-2011.

Rheological Performance Tests: A Dynamic Shear Rheometer (DSR) was employed for these evaluations.

High-Temperature Performance: The complex shear modulus (G) and phase angle (δ) were measured at temperatures of 64°C, 70°C, and 76°C. The rutting resistance was assessed using the rutting factor, G/sinδ.

Intermediate-Temperature Fatigue Performance: Tests were performed at 25°C. The resistance to fatigue cracking was evaluated using the fatigue factor, $G^* \cdot \sin\delta$.

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# 3. Results and Discussion

## 3.1 Effect of Rejuvenator on Conventional Properties

Conventional property tests, namely penetration, softening point, and ductility, were conducted on the aged asphalt with varying rejuvenator contents, and the results are presented in Table 2.

**Table 2.** Conventional performance of asphalt under different dosage of regenerant

| Asphalt type | Regeneration agent dosage(%) | Penetration(0.1mm) | Softening point(°C) | Ductility(5cm, cm) |
|---|---|---|---|---|
| New SBS | 0 | 65 | 78 | 32 |
| Aging SBS | 0 | 38 | 85 | 15 |
| Recycled asphalt | 4 | 45 | 82 | 18 |
| Recycled asphalt | 5 | 52 | 80 | 22 |
| Recycled asphalt | 6 | 62 | 79 | 29 |
| Recycled asphalt | 7 | 70 | 76 | 31 |

As observed in Table 2, the penetration of the aged asphalt significantly increased, the softening point decreased, and the 5°C ductility markedly improved with increasing rejuvenator dosage. These trends indicate that the rejuvenator effectively softened the aged asphalt, reducing its viscosity and enhancing its plasticity.At the optimal rejuvenator dosage of 6%, the penetration and softening point of the rejuvenated asphalt closely matched those of the virgin SBS-modified asphalt. Furthermore, the 5°C ductility reached 29 cm, a value that not only signifies substantial recovery but even exceeds the 32 cm of the original asphalt, demonstrating the exceptional capability of the rejuvenator in restoring and optimizing low-temperature flexibility. This enhancement is primarily attributed to the effective dilution of the asphaltenes that agglomerated during the aging process by the soft components in the rejuvenator, which facilitates the reformation of a stable colloidal structure. A schematic diagram illustrating this reconstruction mechanism is provided in Fig .1.

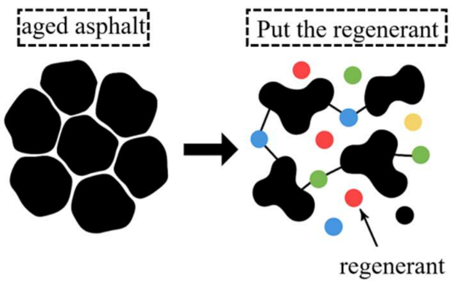


**Fig.1** Schematic diagram of component blending and structural reorganization mechanism of rejuvenator on aged asphalt

## 3.2 Optimization of Rheological Properties by Rejuvenator

To more comprehensively evaluate the service performance of the rejuvenated asphalt, its high-temperature and intermediate-temperature rheological characteristics were assessed using a Dynamic Shear Rheometer (DSR).

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### 3.2.1 High-Temperature Performance Analysis

The rutting factor, G*/sinδ, serves as a key indicator for evaluating the resistance of asphalt to permanent deformation at high temperatures, where a higher value denotes superior rutting resistance. The corresponding test results are presented in Fig.2.

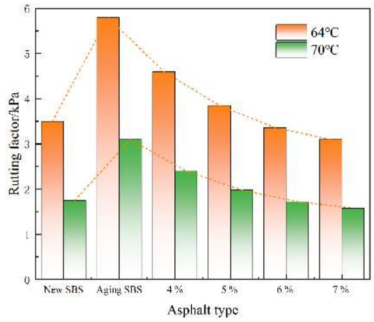


**Fig.2** Comparison of different asphalt rutting factors (G */sinδ)

As shown in Fig. 2, the rutting factor of the asphalt increased markedly after aging, indicating a rise in its high-temperature stiffness. While this suggests an initial enhancement in rigidity, it is accompanied by a considerable loss of toughness, rendering the material more prone to cracking. The introduction of the composite rejuvenator effectively reduced the rutting factor. At the optimal dosage of 6%, the rutting factor values of the rejuvenated asphalt at 64°C and 70°C were measured at 96% and 94% of those of the virgin SBS-modified asphalt, respectively. This result confirms that the high-temperature performance was effectively restored, while simultaneously maintaining excellent resistance to rutting.

### 3.2.2 Intermediate-Temperature Fatigue Performance

The fatigue factor, G*·sinδ, characterizes the asphalt's ability to resist fatigue cracking under repeated loading, with a lower value indicating superior fatigue performance. The test results obtained at 25°C are summarized in Table 3.

**Table 3.** Fatigue factor (G *·sinδ) and relative fatigue life of different asphalts at 25℃

| Asphalt type | Regenerant dosage(%) | G*·sinδ(kPa) | Relative fatigue life |
|---|---|---|---|
| New SBS | 0 | 1250 | 1.82 |
| Aging SBS | 0 | 2270 | 1.00 (bench mark) |
| Recycled asphalt | 5 | 1680 | 1.35 |
| Recycled asphalt | 6 | 1420 | 1.60 |
| Recycled asphalt | 7 | 1350 | 1.68 |

Based on the classical fatigue life prediction model[10], the fatigue life (N_f) is proportional to 1/(G*·sinδ). Therefore, the relative fatigue life of other asphalt binders was calculated using the aged asphalt as the baseline (1.00).

As can be seen from Table 3, the aged asphalt exhibited the highest fatigue factor, indicating the poorest fatigue resistance. After the rejuvenator was introduced, the fatigue factor was significantly reduced. At the optimal dosage of 6%, the fatigue factor was measured at 1420 kPa, and the corresponding relative fatigue life reached 1.60 times that of the aged asphalt, representing an improvement of approximately 60%. Even when compared to the virgin SBS-modified asphalt, its

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fatigue resistance was restored to about 88%. This indicates that the flexibility of the asphalt was effectively restored by the rejuvenator, leading to a substantial improvement in pavement durability.

### 3.3 Determination of Optimal Rejuvenator Dosage and Comprehensive Performance Evaluation

Based on a synthesis of the above experimental results, the following conclusions can be drawn:

At Insufficient Dosages (4%-5%): The hardness and brittleness of the asphalt were not sufficiently alleviated. The restoration of both low-temperature ductility and fatigue resistance was found to be inadequate.

At Excessive Dosages (7%): Although excellent low-temperature performance was achieved, the high-temperature performance (as indicated by the softening point and rutting factor) was observed to be excessively compromised, potentially affecting the high-temperature stability of the recycled asphalt mixture.

At the Optimal Dosage (6%): At this content, an optimal balance was achieved among the high-temperature, low-temperature, and fatigue performance of the rejuvenated asphalt. Its conventional indicators were found to be comparable to those of virgin asphalt, its rheological properties were restored to over 90% of the virgin asphalt's level, and its low-temperature ductility was notably optimized.

## 4. Conclusion

The composite rejuvenator investigated in this study effectively reverses the aging process of SBS-modified asphalt. By replenishing the light fractions and reconstructing the colloidal structure, it comprehensively restores both the conventional and rheological properties of the aged asphalt.

The rejuvenator dosage is a critical factor influencing the regeneration efficacy. For the specific aged asphalt in this study, the optimal dosage was determined to be 6%. At this dosage, the penetration of the rejuvenated asphalt recovered to 95% of the virgin benchmark, its softening point was essentially consistent with the original asphalt, and its 5°C ductility even surpassed that of the original asphalt, demonstrating superior low-temperature flexibility.

Rheological analysis confirmed that the rejuvenated asphalt with a 6% dosage exhibited a high-temperature rutting resistance ($G^*/\sin\delta$) recovery of over 94% compared to the virgin asphalt. Furthermore, its intermediate-temperature fatigue life was increased by approximately 60% relative to the aged state, indicating excellent overall pavement performance.

This research confirms that by employing a suitable rejuvenator and a scientific mix design, hot in-plant recycling technology can not only address the environmental concerns associated with RAP but also produce high-performance recycled asphalt mixtures. It represents a key technology for achieving green, efficient, and long-life maintenance of asphalt pavements.

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