Investigation on performances of hot in-place recycling porous asphalt mixture

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ABSTRACT: This study focuses on the performance of hot in-place recycled porous asphalt mixture, which is considered as a low-carbon maintenance technology of porous asphalt pavement using high-viscosity modified asphalt as the binder. Based on practical engineering project, the performance of aged high-viscosity modified asphalt was analyzed, and the effects of plant-based oil and petroleum-based rejuvenators at varying contents were compared. The influences of different proportions of new porous asphalt mixtures on recycled mixture performance and the impact of basalt fiber on asphalt drain-down were also evaluated. Finally, observations from the field trial section were conducted to assess the performance of the recycled mixtures and pavement permeability. The plant-based oil rejuvenator demonstrated superior recovery performance for aged asphalt. The proportion of new added porous asphalt mixture was set at 15%. The drain-down loss percentage of the mixture dropped to 0.4% with the addition of basalt fiber. All performance indicators measured on the on-site trial section met design requirements, and the permeability coefficients exceeded the design value of 3600 mL/min. The results demonstrate that hot in-place recycling effectively restores the performance and permeability of porous asphalt mixtures, providing a sustainable maintenance method for porous asphalt pavements.

1 INTRODUCTION

Porous asphalt pavement is typical road surface used to enhance driving safety in rainy weather, mitigate traffic noise pollution and facilitate low-impact development. The surface layer is paved by porous asphalt mixture (PA) with a porosity of 18-25%. Research and applications both domestically and internationally indicate that the service life of the porous surface layer is generally 10-15 years (Nielsen. 2006, Takahashi. 2013). Due to the limited contact area between coarse aggregates in porous asphalt pavement, the contact forces between particles become relatively high under load. Repeated traffic loading can lead to coarse aggregate detachment, known as raveling, caused by insufficient adhesion between asphalt and aggregate or mastic fracture (Manrique-Sanchez et al. 2016, De Visscher et al. 2017). Once such disease occurs locally, it will accelerate aggregate raveling in adjacent areas and significantly impacting the pavement's service life, driving comfort, and safety. Currently, maintenance strategies for porous asphalt pavement at various service stages include: (1) preventive maintenance by spraying restorative and strengthening emulsion materials; (2) local damage repair using porous permeable resin materials;(3) overlaying thin layers for addressing medium aggregate loss over long sections (Chen et al. 2023, Li et al. 2021). For porous asphalt pavement at the end of its service life, it is usually milled and the surface layer is repaved. Since the raw materials of porous asphalt mixture are mostly high-quality asphalt and mineral aggregates, material waste or downgrading use will inevitably cause great resource waste. Under the "carbon peaking and carbon neutrality" goals and promoting sustainable development, developing efficient, high-performance, and low-emission recycling methods for end-of-life porous asphalt mixtures has become one of the most pressing and significant challenges in the field of pavement engineering.

Hot In-Place Recycling (HIR), also known as on-site hot recycling or in-place hot recycling, is an efficient, rapid, and environmentally friendly asphalt pavement maintenance technology. Through the process of heating, scarifying, and repaving the asphalt pavement in place, it achieves 100% in-place recycling of the old pavement. Since the beginning of this century, the hot in-place recycling technology has developed rapidly in China. At present, key equipment such as heating and scarifying equipment, as well as recycling agent materials, have been domestically produced. HIR has become a critical pavement maintenance technology in some regions of China. Similarly, countries like the Netherlands and Japan, which have extensively adopted porous asphalt pavements, have validated the feasibility of HIR for porous asphalt through trial sections (van de Pol. 2019, Kayedi et al. 2017).

This study focuses on porous asphalt pavements in China constructed with high-viscosity modified asphalt (HVMA) as the binder. Investigation on characteristics of aged asphalt, recycled mixture, and pavement were carried out. Field application was also carried out to verify the practical effectiveness of HIR for porous asphalt mixtures. The achievements from this study provide foundational support for efficient and low-carbon maintenance of aged porous asphalt mixtures.

2 INVESTIGATION ON AGED BINDER

2.1 *Recycled asphalt*

This study focuses on the performance analysis of porous asphalt mixtures from G2513 Huai'an-Xuzhou Expressway. The porous asphalt pavement on this section was originally constructed in 2015, and samples were collected in 2023, which represents a service life of 8 years. Sampling was carried out to a depth of 4 cm, which is equal to the full thickness of the porous asphalt mixture. The collected mixture from the pavement was subjected to dust removal. And the aged asphalt was extracted using rotary evaporation and centrifugal separation methods. The asphalt-aggregate ratio of the reclaimed asphalt mixture from the old pavement was measured at 4.74%, showing a slight reduction compared to the original pavement's ratio of 4.8%. Subsequently, the main performances of the aged asphalt were measured, with the results shown in Table 1. In this study, all tests for asphalt and asphalt mixtures were conducted in accordance with the Chinese specification JTG E20 "Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering." It finds that there are significant changes in the performances of the HVMA compared to its original state. Overall, the aged asphalt exhibited a pronounced trend of hardening and severe aging. Therefore, the use of rejuvenators is essential to restore the aged asphalt's performance properties effectively.

Table.1 Key performance indicators of old asphalt

Performance Indicators	Recycled bitumen	Original	Requirement*
25℃ Penetration/0.1mm	15.8	44	≥40
Softening Point/℃	＞117	98	≥80
5℃ Ductility/cm	Broken	35	≥30
Dynamic Viscosity/Pa•s	>1,000,000	440,806	≥50,000

*According to Chinese Transportation industrial specification "Technical Specifications for Design and Construction of Porous Asphalt Pavement" (JTG/T 3350-03-2020).

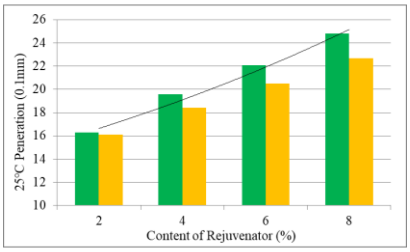
2.2 *Effects of rejuvenator*

The current heating process for hot in-place recycling typically requires a paving temperature of no less than 135°C. However, for porous asphalt mixtures, which have higher viscosity, the paving temperature generally needs to exceed 155°C. For better remixing, the liquid rejuvenators with warm-mix properties were used in this study. Comparative experiments were conducted using two types of rejuvenators: a plant-based oil rejuvenator RR18 and a petroleum-based PR-01. The technical indexes of the two rejuvenators were shown in Table 2. After the aged asphalt was heated to 160℃, a set amount of rejuvenator was added. The subsequent performance tests were carried out after mixing evenly.

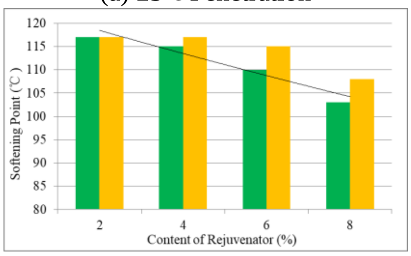
Rejuvenators were added to aged asphalt at ratios of 2%, 4%, 6%, and 8%, and performance indicators such as penetration, softening point, and viscosity were measured. The test results are shown in Figure 1. Considering the practical emphasis on the workability of mixtures during in-place recycling, Brookfield viscosity tests at 170°C were also conducted. The results indicate that penetration increases with the addition of rejuvenators, while both softening point and Brookfield viscosity show a decreasing trend. This suggests that as the rejuvenator content increases, the performances of aged HVMA is restored to some extent, and the degree of recovery improved proportionally to the rejuvenator content. As to the two types of rejuvenators, the plant-based oil rejuvenator (RR18) demonstrated superior recovery effects on aged HVMA compared to the petroleum-based rejuvenator (PR-01).

Table.2 Performance indicators of two rejuvenators

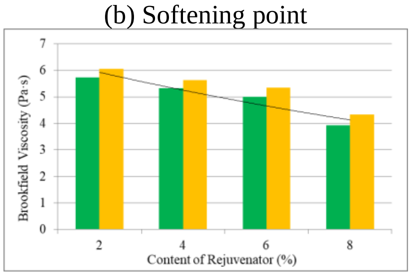
Performance Indicators		RR18	PR-01
25℃viscosity / Pa•s		72	/
After TFOT aged test	Residual viscosity ratio(%)	2.9	/
	Mass change rate(%)	0.288	0.262



(a) 25℃Penetration



(b) Softening point



(c) 170℃ Brookfield viscosity

Figure 1.Effects of rejuvenator on performances of recycled asphalt.

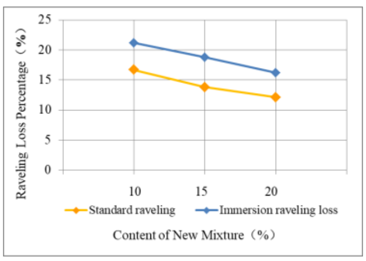
3 INVESTIGATION ON RECYCLED MIXTURE

3.1 *Influence of new mixture*

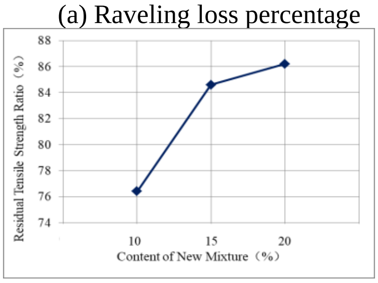
In order to compensate for the loss of mixture caused by rutting, raveling etc., to recover the performance of porous asphalt mixture, and optimize the gradation of recycled asphalt mixture, it is necessary to add a portion of new asphalt mixture. In order to ensure the porosity of the recycled mixture, the newly added asphalt mixture is still a porous asphalt mixture. HVMA is used as the binder, with an optimal asphalt to aggregate ratio of 4.9%. The design voids content of the mixture is 22.0%. The blending percentage of the new porous asphalt mixture in the total mixture are set at 10%, 15%, and 20%, aiming for a final void ratio of 18.0% in the recycled mixture. The amount of RR18 rejuvenator was 4% in the asphalt. Consequently, RR18 was selected as the primary rejuvenator for subsequent mixture experiments.

The performances of recycled porous asphalt mixtures with varying amounts of new material were measured, including raveling resistance, freeze-thaw splitting, low-temperature bending, and high temperature dynamic stability. The experimental results are shown in Figure 2.

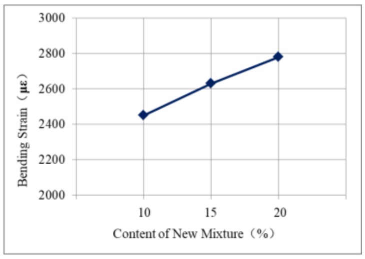
As can be seen from the figure, with the increase of the new porous asphalt mixture ratio, the raveling loss percentages for both the standard and after immersion decrease, and the residual freeze-thaw splitting tensile ratio and low-temperature bending strain increase. This indicates that the resistance to raveling, water damage, and low-temperature damage of the recycled asphalt mixture are improved. For the dynamic stability, it shows a decrease trend with increasing percentage of new mixture. It can be explained as that the addition of new asphalt mixture increases the proportion of fresh binder, softening the overall asphalt and slightly reducing rutting resistance. However, the dynamic stability remains above 6000 times/mm, reflecting a high performance of rutting resistance.



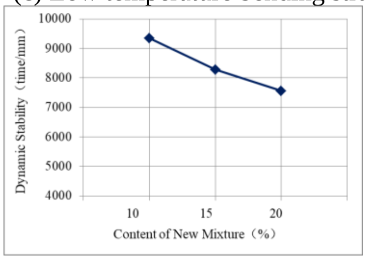
(a) Raveling loss percentage



(b) Residual freeze-thaw split tensile strength ratio



(c) Low temperature bending strain



(d) 60℃ Dynamic stability

Figure 2.Effects of new mixture content on performances of recycled porous asphalt mixture.

3.2 *Influence of fiber*

Porous asphalt mixtures, due to their high air void content, are susceptible to asphalt stripping from aggregate voids. The addition of fibers in asphalt mixtures can play an important role in absorbing and stabilizing the asphalt binder, thereby enhancing the adhesion between aggregates and reducing the stripping of asphalt binder from the voids. To improve the workability of mixtures during long-distance transportation, 0.3% basalt fiber by total mass was added into the new porous asphalt mixture. Asphalt drain-down tests were conducted on mixtures prepared with different asphalt-aggregate ratios, and the results are shown in Figure 3.

The findings demonstrate that the addition of 0.3% basalt fiber help to reduce the drain-down loss of the porous asphalt mixture. At the optimal asphalt-aggregate ratio of 4.9%, the drain-down loss percentage of the mixture without fiber was 1.2%, while it dropped to just 0.4% with the inclusion of basalt fiber. These results indicate that the addition of basalt fiber can enhance the workability of new porous asphalt mixtures during long-distance transportation by reducing binder drain-down and maintaining material stability.

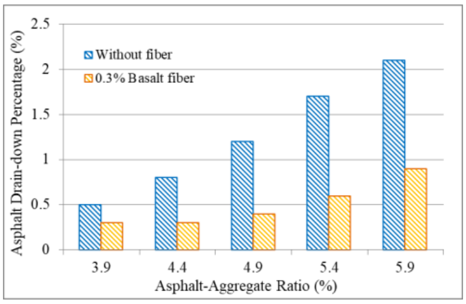


Figure 3. Asphalt drain-down percentage at different asphalt-aggregate ratio.

4 INVESTIGATION ON TRIAL SECTION

4.1 *Mixture performance*

The hot in-place recycling project for porous asphalt pavement was implemented on the G2513 Huai'an-Xuzhou Expressway. Samples were collected from the trial section, and performance tests were conducted on the recycled asphalt mixture, with the results presented in Table 3. According to the table, all performance indicators met the design requirements. The residual stability and freeze-thaw splitting tensile strength were comparable to those of new porous asphalt mixtures. However, the raveling loss of the recycled mixture was higher than that of the new porous asphalt, indicating that asphalt ageing has adverse effect on the raveling resistance of the recycled mixture. It can be improved by adding suitable percentage of new mixture.

Table.3 Test results on recycled mixture

Performance Indicators	Test Results	Design Target
Voids content（%）	17.4	≥16
Marshall stability（kN）	16.2	≥5
Drain-down percentage（%）	0.073	≤0.8
Standard raveling loss（%）	14.7	≤15
Immersion raveling loss（%）	18.0	≤20
Dynamic stability（time/mm）	8796	≥5000
Residual Mashall stability percentage（%）	87.9	≥85
Residual Freeze-thaw split tensile strength ratio（%）	87.5	≥80

4.2 *Permeability*

Permeability coefficients were tested on-site at ten locations before and after recycling, with the results shown in Figure 4.

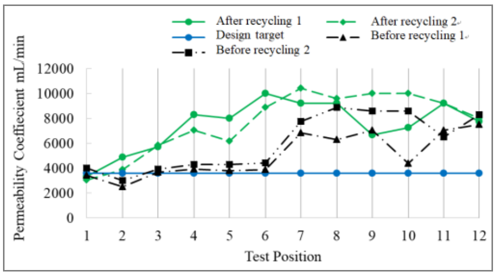


Figure 4. Permeability on the recycling section.

As indicated in the figure, except for location 1, the permeability coefficients at all other locations after recycling exceeded the design value of 3600 mL/min. Notably, locations 3 to 6, which initially exhibited poor permeability, showed significant improvement in performance after recycling. This demonstrates that the hot in-place recycling process can effectively restore the permeability performance of porous asphalt pavements.

5 CONCLUSIONS

Following conclusions can be drawn from this study:

(1) The plant-based oil rejuvenator demonstrated superior recovery performance for aged HVMA. As the rejuvenator content increased from 2% to 8%, the light components in the asphalt were replenished, resulting in better softening of the binder.

(2) The addition of new porous asphalt mixture helps to improve the performance of the recycled asphalt mixture. As the proportion of new material increased, the recycled mixture exhibited enhanced resistance to raveling, improved water stability, and better low-temperature performance. Although dynamic stability decreased slightly, the rutting resistance remained satisfactory.

(3) Performance tests of recycled porous asphalt mixtures from the on-site trial section showed that all indicators met design requirements, and the permeability performance was successfully restored. These findings confirm that hot in-place recycling is a viable maintenance method for porous asphalt pavements.

This study primarily focused on analyzing the macroscopic properties of hot-in place recycled porous asphalt mixtures. Future research will delve into the aging and recovery mechanisms of HVMA and explore the microstructural characteristics of recycled porous asphalt mixtures.

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