Hot-in-place recycling engineering application of low penetration aged asphalt

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Abstract. Hot-in-place recycling of asphalt pavement is one of the important regeneration technologies of pavement engineering, which apply to the pavements with fewer diseases, excellent driving quality, slight rutting, and good pavement structural strength. However, the surface layer of some road sections was aging, the penetration index of aged asphalt at 25°C is lower than 20(0.1mm), which does not meet the recommended requirements of the criterion in China. In 2019, 3 sections of test projects were laid on the expressway, each section was 1 km, for confirming the feasibility of using hot-in-place recycling with asphalt penetration less than 20 (0.1mm) through physical engineering. Experimental results confirmed that Marshall stability, residual stability, dynamic stability and water seepage of the hot-in-place recycled mixture optimized by the recycled pavement material with a penetration of aged asphalt of 15 can meet the specification requirements, Pavement Condition Index (PCI), International Roughness Index (IRI), and Rut Depth (RD) of the test pavements are in good conditions.

Keywords: Asphalt pavement; hot-in-place recycling; the penetration index; pavement condition index; International Roughness Index; Rut Depth.

1. Introduction

Hot-in-place recycling of asphalt pavement is one of the important regeneration technologies of pavement engineering. This kind of technology first heats and softens the original asphalt pavement to facilitate loosening or milling to a certain depth, and then fully mixes the old pavement material with new asphalt mixture and regeneration agent. Mixing, and finally paving and rolling equipment to complete the asphalt pavement regeneration, 100% of the original asphalt pavement can be recycled on site, and can effectively deal with rutting, bagging, oil flooding, poor flatness, water seepage, polishing, pumping, Diseases such as loosening and peeling.

The hot-in-place recycling process of asphalt pavement has many advantages: maximum utilization of resources; reduction of vehicle load; strong functionality of restored pavement; little impact on traffic; fast and convenient process, etc.

The hot-in-place recycling has little contribution to the structural strength of the pavement, and its pavement effect and service life are significantly affected by the structural strength of the original pavement. In china, for damaged road sections, the "Technical Specifications for Highway Asphalt Pavement Recycling" (JTGT5521-2019) [1] recommends that when hot-in-place recycling is used, the technical condition of the pavement should satisfy that the structural strength index of the pavement is not less than 80, and the penetration of aged asphalt within the regeneration range is not less than 20 (0.1mm), the aged asphalt content is not less than 3.8%.

In the past 10 years, more than 3,000 kilometers of expressways have been built and opened to traffic in Jiangxi Province[2]. The typical characteristics of these roads are that the daily traffic volume of the road is not large, the strength of the pavement structure is good, and only the friction performance of the road surface is reduced, polished, loose and peeling. Such as surface functional damage, the use of hot-in-place recycling process can effectively improve the pavement function and repair surface diseases. However, before designing the construction scheme of hot-in-place recycling, after investigating the actual pavement usage conditions and analyzing the material properties, we found that the surface layer of some road sections was aging due to factors such as asphalt aging during the construction stage and long-term exposure to the sun and rain during the service stage. The penetration index of asphalt at 25°C is lower than 20(0.1mm). Since this index does not meet the recommended requirements of the code, the application of hot-in-place recycling is limited.

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The asphalt pavement of an expressway in southern China has fewer diseases, excellent driving quality, slight rutting, and good pavement structural strength. In the design stage of the pavement maintenance project of the "13th Five-Year Plan" in 2019, the asphalt pavement plan for some road sections was adopted. Geothermal regeneration construction plan, but according to the requirements, samples were taken from the original asphalt pavement, and the aged asphalt was extracted and distilled. After conducting the penetration test, it was found that the asphalt penetration of the taken samples was less than 20 (0.1mm), which did not meet the technical requirements. However, considering the short construction period of this project, the focus on improving the road service level, and the small overall maintenance scale, the hot-in-place recycling is still a better technical transformation process. In response to this problem, considering the recommended index of "the penetration index at 25°C is not less than 20 (0.1mm)" in the specification, in 2019, 3 sections of test projects were laid on the expressway, each section was 1 km, in order to demonstrate the feasibility of using hot-in-place recycling for road sections with asphalt penetration less than 20 (0.1mm) through physical engineering.
In this paper, the data collected from the 3 test projects over the past three years are summarized and evaluated.

2. Methodology

2.1 Materials

2.1.1 Asphalt

The type and grade of new asphalt selected for hot-in-place recycling should be consistent with the asphalt used for the original road surface, and asphalt with a higher penetration degree can also be used.
The on-site hot-in-place recycling project uses the same grade of SBS modified asphalt as the original pavement, and the performance indicators of the asphalt meet the requirements of the specification[3]. The test results are shown in Table 1.

Table 1. Properties of the newly mixed SBS asphalt tested

Index		Unit	Qualified range	Result	Judgment
Penetration（25℃、100g、5s）		0.1mm	40～60	52	Yes
Extensibility（5cm/min、5℃）		cm	≥20	30	Yes
Softening point（global approach）		℃	≥60	78.0	Yes
segregation (Difference of softening point between 48H)		℃	≤2.5	1.5	Yes
After RTFOT	Weight change	%	≤±1.0	-0.209	Yes
	Penetration ratio（25℃）	%	≥65	67	Yes
	Extensibility（5℃）	cm	≥15	16	Yes

2.1.2 Aggregate

The lithology of the aggregate used in this project is the same as that of the original road surface. The fine aggregate is machine-made sand whose parent material is limestone, and the filler is mineral powder ground from limestone, which is dry and clean and can flow freely from the mineral powder bin. The performance testing indicators of each grade of aggregate meet the requirements of the corresponding specifications.

2.1.3 Recycled pavement material

The recycled pavement materials used in the laboratory are sampled from the asphalt pavement of the selected test section of the expressway. The samples need to be dried at a temperature of 105°C before use to fully drain the water. The aged asphalt and sieved gradation compositions in recycled pavement materials are shown in Table 2-Table 3, respectively.

Table 2. Properties of the recycled asphalt tested

Index	Qualified range	Result
Penetration（25℃、100g、5s）	≥20	16
Asphalt content（%）	≥3.8	4.4

Table 3. Sieving Test Results of Recycled Pavement Materials

Sieve aperture（mm）	Mass percentage passing through the following square hole sieve（%）									
	16.0	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
1#	100	99.1	91.8	74.1	45.5	32.5	23.5	14.6	7.8	5.2
note	1# is the mineral material gradation after extraction of recycled pavement materials									

2.1.4 Asphalt rejuvenator

Considering the aging degree of the pavement asphalt in this project, we choose two kinds of asphalt rejuvenators for comparison, namely asphalt rejuvenator A produced in China and asphalt rejuvenator B imported from the Netherlands.
The test method is to add regenerated agent according to 3% and 5% of the amount of aged asphalt from indoor standard tests[4], and stir at 145°C and 600rpm for 30 minutes to measure the penetration of recycled asphalt to see if it meets the requirements, and therefore to determine the type and amount of regenerant, the test results are shown in Table 4 below.

Table 4. Penetration test results of recycled asphalt

Sample	Dosage	Result	Qualified range
A1-1	3%	25	40-60
A1-1	5%	35	40-60
B2-1	3%	30	40-60
B2-1	5%	45	40-60
Note	Asphalt aging to a penetration of 15 in test		

It can be seen from Table 4 that the effect of asphalt rejuvenator B is better than that of A, and the two dosages of A cannot meet the project requirements. According to the analysis of the project team personnel, it may be due to the limitation of the regulations that the asphalt rejuvenator produced by company A has no consideration for using aged bitumen with a penetration below 20. Therefore, a 5% dosage of B asphalt rejuvenator was used to carry out the next asphalt mixture test.

The asphalt rejuvenator is PrePhalt FBK imported from the Netherlands. Through the determination of the dosage test, it has good compatibility with the aging asphalt of this project and certain anti-aging performance, it also can ensure the durability of the recycled asphalt and asphalt mixture. It has been verified by experiments that the flash point of the asphalt regenerant is above 220°C.

2.1.5 Newly added asphalt mixture

For the newly added mixture used for remixing, according to the gradation of the recycled asphalt mixture (RAP) mineral material and the performance requirements of the recycled pavement, determine its gradation composition, and test the performance of the recycled mixture; the newly added asphalt mixture When its performance does not meet the relevant provisions of JTG F40[3], if the quality of recycled asphalt mixture meets the relevant provisions of JTG F40, it can be used.

In order to determine the newly added asphalt mixture gradation and asphalt ratio index, in addition to the road performance requirements of recycled asphalt mixture, construction operability, transportation, storage and other factors should also be considered.

2.2 Proportion Design of Recycled Asphalt Mixture

Before the mix design of recycled asphalt mixture, firstly, we evaluated the technical performance of original asphalt pavement and recycled asphalt pavement materials.

In the mix design of recycled asphalt mixture, secondly, we consider the mix ratio and disease characteristics of the original pavement asphalt mixtures, and carry out the mix ratio design of the recycled mixture in a targeted manner. Therefore, the type of recycled asphalt mixture is selected to be consistent with that of the original pavement asphalt mixture, as shown in Figure 1.

The mix design of recycled asphalt mixture also takes into account the actual operating conditions of the recycling plant, as well as the characteristics of the construction organization and the convenience of construction. It is required that production, mixing, spreading and compaction are easy to carry out.

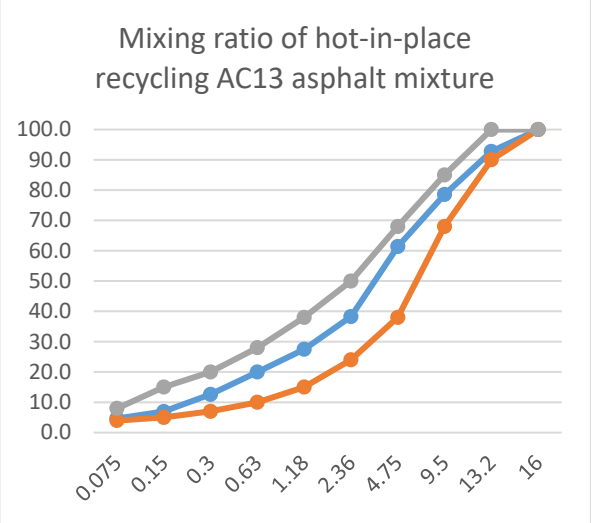

Fig. 1. Mineral grading curve of hot-in-place recycling AC-13C asphalt mixture

2.3 Asphalt mixture tests and pavement technical condition inspection

In order to ensure the quality of the recycled mixture, during the construction of the test section, we tested the road performance indicators such as Marshall stability, residual stability, dynamic stability and water seepage of the rutted plate of the recycled mixture.

After the completion of the paving of the test section, every year we examined pavement condition index (PCI), International Roughness Index (IRI), and Rut Depth (RD)to reflect the technical condition of the pavement.

3. Results and discussion

3.1 The road performance indicators

Based on experimental verification, when the hot-in-place recycling AC-13C asphalt mixture has an optimal asphalt ratio of 5.0%, all technical indicators of the asphalt mixture meet the requirements of JTG F40-2004 [3]("Technical Specifications for Construction of Highway Asphalt Pavement "), as shown in Table 5.

The results also show that the performance of the recycled asphalt mixture with the selected type and amount of asphalt rejuvenator can meet the requirements of the Chinese industry norms and the actual requirements of the project.

Obviously, the technical indicators such as Marshall stability, residual stability, dynamic stability and water seepage of the hot-in-place recycled mixture optimized by the recycled pavement material with a penetration of aged asphalt of 15 meet the specification requirements.

Table 5. Test results of recycled asphalt mixture

No.	Index	Unit	Qualified range	Result	Judgment
1	Marshall stability	kN	≥8	12.36	Yes
2	Flow value	mm	1.5-4.0	1.75	Yes
3	Asphalt saturation	%	65-75	69.1	Yes
4	Gross volume density	g/cm³	/	2.361	/
5	Theoretical maximum density	g/cm³	/	2.473	/
6	Porosity	%	4-6	4.5	Yes
7	VMA	%	≥14.5	14.5	Yes
8	Residual stability	%	≥85	85.3	Yes
9	Dynamic stability	number of times /mm	DS≥2800	3320	Yes
10	Water seepage	ml / min	/	0	Yes

3.2 The technical condition of the test pavements

Before the construction, the design unit entrusted the inspection unit to conduct a full range of inspections on the technical performance of the expressway asphalt pavement (indices such as Pavement Condition Index, International Roughness Index and Rut Depth).

In 2019, we selected 3 road sections of 1 km each (A, B, and C respectively) to carry out the test road verification work. In order to test and observe the technical status of the test road surface, we have carried out the same inspection work for two consecutive years from 2020 to 2021. The detected indicators include PCI, IRI and RD.The same equipment, spanning 3 years, 3 tests, Figure 2 to Figure 4 are the test results.

It can be seen from Figure 2 that after the hot-in-place regeneration, one year later, the PCI condition of the three sections of asphalt pavement improved significantly, with an average increase of 26.5%, and the best result was 100%. After two years of vehicle loading, the average PCI of the test sections was 92%, which is still better than the situation before hot-in-place regeneration in the field, and the average increase of PCI after two years was 17.8%.

It can be seen from Figure 3 that the average International Roughness Index of the three test sections in 2019 was 0.8 m/km, which was in an excellent technical state. After the hot-in-place regeneration, the average level of International Roughness Index is increased to 1.2 m/km, and the maximum value of section A is 1.5 m/km. We all know that the smaller the IRI, the smoother the road surface. Obviously, the construction of hot-in-place regeneration reduces the smoothness of the road surface. Even so, the smoothness of the road surface in 2019 is very good and rare, and the smoothness of the road surface after construction in 2020 still meets the requirements of Chinese standards[5]. With road traffic running smoothly, the average IRI of the three test roads returns to 1.1 m/km in 2021.

It can be seen from Figure 4 that there were basically no road ruts on the three test roads in 2019, with an average Rut Depth of 4.8mm. This state also corresponded to the excellent road smoothness mentioned above. In 2020, after the hot-in-place regeneration construction treatment, the average rut depth of the test roads reduced to 3.3mm. Two years later, in 2021, the rut depth of the test roads still maintain an excellent level of 4.0mm on average.

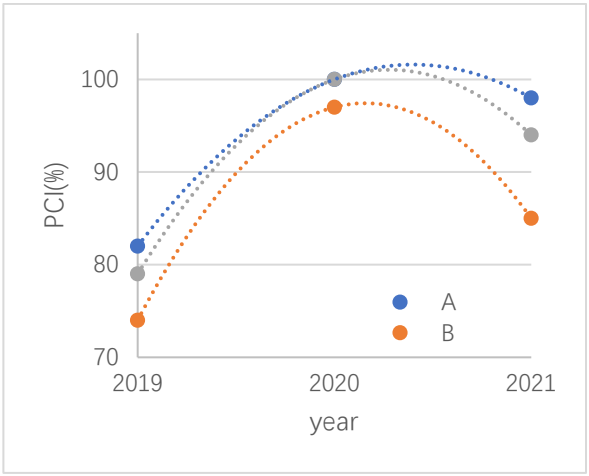

Fig. 2. Pavement condition index of the test road

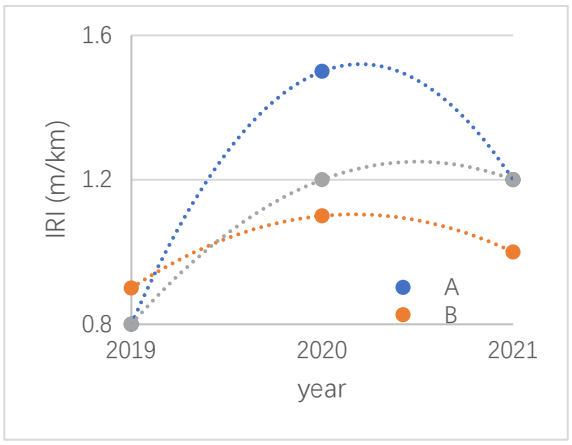

Fig. 3. International Roughness Index of the test road

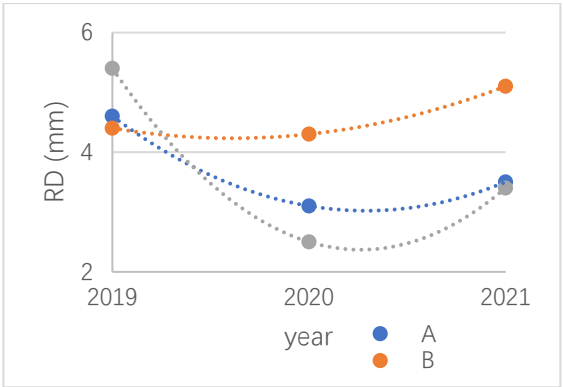

Fig. 4. Rut Depth of the test road

4. Conclusions

A large number of asphalt pavements with sufficient pavement structural strength and excellent pavement technical condition were found to have a penetration index of aged asphalt that could not meet the specification requirements after the hot-in-place regeneration process in the maintenance project to improve the service function level of the pavement. We selected three highway sections with aging asphalt penetration of 16(0.1mm) to carry out experimental research. The conclusions are as follows:
(1) The technical indicators such as Marshall stability, residual stability, dynamic stability and water seepage of the hot-in-place recycled mixture optimized by the recycled pavement material with a penetration of aged asphalt of 15 can meet the specification requirements.
(2) After the hot-in-place regeneration, the PCI condition of asphalt pavement improve significantly. After two years of vehicle loading, the average PCI of the test sections is still better than the situation before hot-in-place regeneration.
(3) The construction of hot-in-place regeneration may cut down the smoothness of the road surface, but the International Roughness Index can meet the requirements of Chinese standards.
(4) The hot-in-place regeneration can heal road ruts and maintain the Rut Depth of the pavement in a smaller state.

Acknowledgments

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