Design and Engineering Application of Asphalt Pavement Maintenance Schemes for Heavy-Traffic Intersections

Liujie Guo*, Changxiaoxi Liu[a], Yongcai Yang[b], Yanhe Sui[c]

RoadMainT Co., Ltd., Beijing, 100095, China

*guoliujie@roadmaint.com, [a]liuchangxiaoxi@roadmaint.com, [b]yangyongcai@roadmaint.com, [c]suiyanhe@roadmaint.com

Abstract. This paper conducts maintenance scheme design and material performance research based on the S218 Provincial Road intersection treatment project. On the one hand, it accurately identifies the causes of pavement diseases by carrying out special inspection work such as on-site core drilling and sampling, pavement pit exploration tests, pavement structure strength detection, ground radar detection, and drainage facility investigation. On the other hand, taking the AC-13 gradation as an example, the mix proportion design and road performance research of three modified asphalt mixtures were carried out. The polymer resin modifier (AR-3) modifier can increase the optimal oil-to-stone ratio of asphalt mixtures, endowing them with excellent low-temperature crack resistance. The Marshall stability has increased by approximately 25%, demonstrating excellent high-temperature stability. Under high-temperature and heavy-load conditions (dynamic stability at 70℃ and 1.0Mpa), the anti-rutting capacity can reach 2.5 times the technical standard. Both the indoor test research and the on-site engineering detection results show that the polymer resin modifier (AR-3) has better comprehensive road performance and can effectively delay the development of pavement diseases when applied to intersection sections.

Keywords: Intersection, Scheme design, Road performance, Effect evaluation

1 Introduction

Due to the influence of low-speed driving of heavy vehicles, water release braking, and frequent start-stop, the road surface at ordinary national and provincial trunk highway intersections shows relatively serious diseases within a short period after major and medium repairs [1,2], such as rutting, displacement, cracking, and particle scattering [3]. This leads to the maintenance units having to invest a huge amount of human, material and financial resources in repeated maintenance and repair. The main reasons include two aspects: scheme design and material performance. At the level of scheme design, compared with regular sections, the degree of pavement diseases at the intersections of ordinary national and provincial trunk roads is often more severe, and special pavement maintenance design is required to thoroughly treat the original pavement diseases. In terms of material performance, the shear stress that the road surface at intersections

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bears is much greater than that of conventional sections, especially in high-temperature and rainy areas and sections with heavy traffic. The shear strength of traditional SBS modified asphalt or high modulus asphalt mixtures is insufficient to resist the action of traffic loads, thus causing rutting and other diseases [4,5]. To address this issue, the industry has attempted to use high-modulus anti-rutting agents or high-content SBS modified asphalt, or even epoxy asphalt to enhance the durability of asphalt pavements. However, due to reasons such as insufficient road performance, complex construction techniques, and high project costs, the application effects have not met expectations [6].

Based on the S218 Provincial Road intersection treatment project in Jiangxi Province, this paper conducts research on the maintenance scheme design and material performance of trunk road intersections to promote the maintenance level of trunk road intersections.

2 Maintenance Plan Design

Provincial Road S218 is an important traffic artery in Gao 'an City, Jiangxi Province, and a key channel for local tile logistics. It carries the economic lifeline of Gao 'an City. However, due to heavy traffic volume and a large number of heavy-duty trucks, the road surface is severely damaged, especially at intersections, where the road's service life is less than three years. The original pavement surface includes both asphalt pavement and reinforced concrete pavement. The pavement structure of asphalt pavement includes 4cm AC-13 upper layer, 6cm AC-16 middle layer, 10cm ATB-25 lower layer and 40cm cement stabilized macadam base. The pavement structure of cement concrete pavement includes 30cm C50 reinforced concrete upper layer and 30cm cement stabilized macadam base.

2.1 Disease Types

The main diseases of the asphalt pavement on this section include ruts, net cracks, potholes and pitted surfaces. The depth of ruts is mostly over 2cm, and in some sections, it exceeds 4cm. There are continuous cracking diseases from K228+610 to K228+680, with a total area of 39 square meters. The main diseases of the cement concrete pavement on the side close to the traffic light intersection include misalignment (height over 3cm), hollowing, as well as local slab breakage and mud pumping, etc. The International Smoothness Index (IRI) is basically above 10m/km, and some sections reach extreme values. The ten-meter road condition detection data of this section of the road is shown in Figure 1.

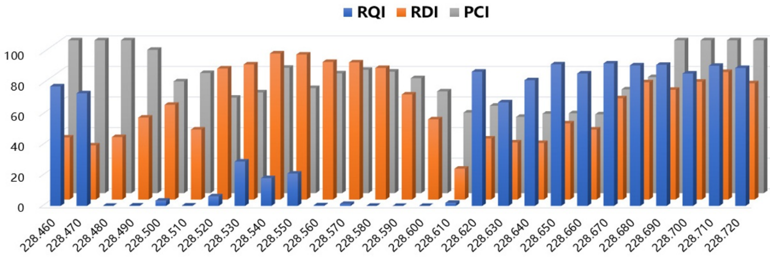

Fig. 1. The technical condition of the original road surface.

2.2 Road Condition Inspection

In order to further analyze the causes and development status of pavement diseases, this paper has respectively carried out special inspection works such as on-site core drilling and sampling, pavement pit exploration tests, pavement structure strength detection, ground penetrating radar detection, and drainage facility investigation.

At a depth of approximately 3cm for the ruts on the asphalt pavement, a core sampling machine with a diameter of 150mm was used to take core samples from the two wheel track zones and the hard shoulder. The results show that the rutting disease of the asphalt pavement in this section mainly includes two types: the compacted rutting on the upper layer and the flowing rutting on the middle layer. The wear of the surface layer also leads to the rutting disease of the pavement. The lower layer 10cm is basically intact, and the upper base layer is intact. In addition, the cracking disease of asphalt pavement is mainly caused by the insufficient fatigue performance of the surface layer material under the long-term action of high-flow and high-load vehicles. The bonding between the surface layers is good, and the bonding between some surface layers and the base layer is also good. See in figure 2.

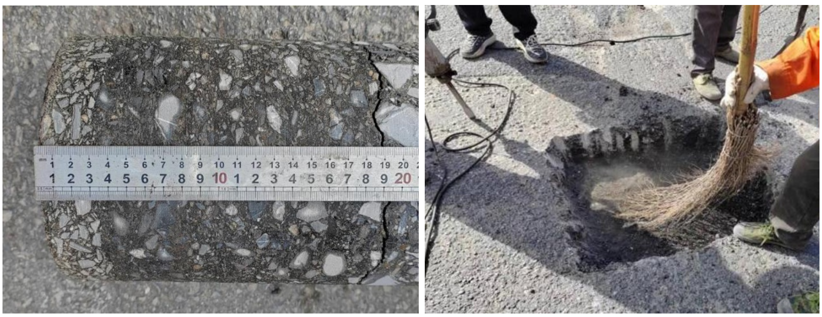

Fig. 2. Surface core drilling sampling and pit exploration test.

The structural strength of both the upward-section and downward-section of the road was simultaneously collected using a Falling Weight Deflectometer. A total of 66 measurement points were tested on the downward overtaking lane and 84 on the downward driving lane. The D0 of over 98% of the sections was less than 15 (0.01mm), among which the proportion of measurement points less than 10 (0.01mm) was 74% and 77% respectively. Overall, the structural strength of the pavement was good. See in table 1.

Table 1. Test results of pavement structure strength.

Lane	Distribution of D_0 measurement points /0.01mm					
	0~5	5~10	10~15	15~20	＞20	total
Upward first lane	2	10	7	2	1	22
Upward second lane	3	44	10	7	0	64
Downward first lane	15	34	15	0	2	66
Downward second lane	25	40	19	0	0	84

Ground-penetrating radar was used to inspect the surface layer and base layer of the pavement. The preliminary results show that there are no water-rich areas in the surface layer and base layer of the asphalt pavement overall (there are no obvious water accumulation diseases inside the structural layer). In the asphalt pavement section, no obvious loosening or damage was observed in the base and subgrade structure. There was a small local void at the starting point, and it was initially judged that the interlayer bonding was poor. The specific location is shown in figure 3. In the cement pavement section, there was no obvious void protruding (possibly affected by the steel mesh). Near the stop line of the intersection, the asphalt pavement has about 10 meters of loose base layer in some local areas, and there is poor bonding between the surface layer and the base layer for 15 to 20 meters.

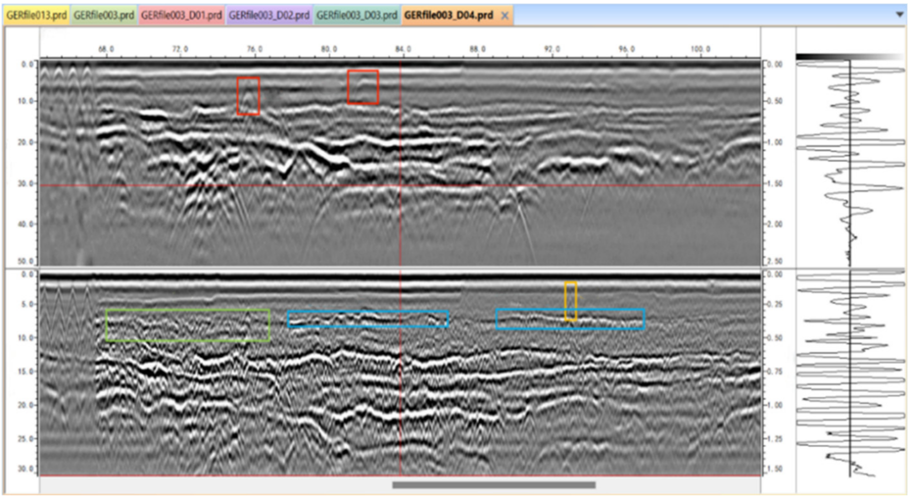

Fig. 3. Ground-penetrating radar detection results. Type of disease:（red）Pavement void disease; (green) Raveling disease; (blue) Poor interlayer bonding disease; (yellow) Cracking disease.

2.3 Maintenance Plan

Based on the above analysis and taking into account factors such as pavement durability, driving comfort, construction organization, and project cost comprehensively, the maintenance plans for asphalt pavement and cement pavement are as follows.

For asphalt pavement, first mill the upper and middle layers, dig out and refill the base layer at the locally loose positions, treat the local diseases of the lower layer, then spread a 1cm thick modified asphalt crushed stone seal layer, and finally re-lay a 4cm thick SBS modified asphalt upper layer and an 8cm thick SBS modified asphalt AC-25 middle layer. To enhance the high-temperature resistance to rutting of the asphalt mixture, 0.5% (by mass) of asphalt mixture modifier is added to both the upper and middle layers of the asphalt mixture.

For cement concrete pavement, first, 30cm of the original cement pavement is removed, and the original 10cm cement-stabilized crushed stone base is milled. Local diseases of the lower base are treated. Then, 20cm of large-particle cement-stabilized crushed stone is re-laid as the upper base. After sprinkling a primer on the surface of the upper base, 1cm of modified asphalt crushed stone seal is spread. Finally, a 4cm thick SBS modified asphalt top layer and an 8cm thick SBS modified asphalt AC-25 middle layer were re-laid, and 0.5% (by mass) of asphalt mixture modifier was added to the asphalt mixture of both the top and middle layers.

3 Research on Material Properties

This paper takes the AC-13 gradation as an example to conduct performance research on the resin modifier AR-3 (mainly composed of high-molecular resin) used in this project, and to carry out the mix proportion design and road performance research of asphalt mixture with two commonly used commercially available anti-rutting agents AR-1 (mainly composed of waste plastic) and rubber-plastic modifier AR-2 (mainly composed of waste plastic and rubber). And conduct a comparison and comprehensive evaluation of the three modified asphalt mixtures.

3.1 Mix Proportion Design

The raw materials used in the experiments of this project are 5-10mm and 10-15mm basalt coarse aggregates, 0-5mm limestone fine aggregates and limestone ore powder produced in Jiangxi Province. The asphalt used is SBS modified asphalt produced in Jiangxi Province. The main technical indicators of the modified asphalt are shown in Table 2.

Table 2. Table captions should be placed above the tables.

Test item	Specification	Result
Penetration (25°C, 100g, 5s) /0.1 mm	40-60	54
Softening point /◦C	≥70	83
Ductility (5 cm/min, 5°C) /cm	≥25	33

Test item		Specification	Result
Elastic recovery (25 °C) /%		≥75	85
Storage Stability, °C		≤2.5	1.5
Viscosity (135°C), Pa.s		≤3.0	1.25
Residue after RTFOT	Mass change /%	±1.0	-0.30
	Penetration ratio /%	≥65	78
	5°C Residual ductility/cm	≥15	16

The mix proportion design of asphalt mixture adopts the Marshall test mix proportion design method. The sieve hole passing rate and mineral material gradation of the initially set synthetic gradation are shown in Table 3.

Table 3. The target mix ratio synthesis gradation of AC-13.

Sieve size /mm	Pass rate /%			
	Upper limit	Lower limit	Median	Synthetic gradation
16	100	100	100	100
13.2	100	90	95	96.0
9.5	85	68	76.5	81.1
4.75	68	38	53	46.3
2.36	50	24	37	30.5
1.18	38	15	26.5	23.2
0.6	28	10	19	16.7
0.3	20	7	13.5	10.1
0.15	15	5	10	7.8
0.075	8	4	6	4.9

Based on the above raw materials and synthetic gradation, the mix proportion design of the asphalt mixture with three different modifiers was carried out. The dosage of the modifiers was 0.5% for each. The forming conditions of the Marshall test piece were as follows: the mixing temperature was 185°C, the compaction forming temperature was 175°C, and the compaction on each side was 75 times. The test results of the three asphalt mixtures are shown in Table 4.

Table 4. Marshall test results of asphalt mixture with three different modifiers added.

Test item	AR-1	AR-2	AR-3	Specification
Optimum oil stone ratio, %	5.0	5.1	5.5	/
Voidage, %	4.2	4.0	4.0	3~5
Voids of Mineral Aggregate, %	14.1	14.3	15.8	≥16.5
Asphalt saturation, %	70.2	72	74.7	65~75
Marshall stability, kN	17.6	18.8	24.5	≥15
Flow value, mm	3.1	3.5	4.5	2~5

It can be seen from Table 4 that the optimal oil-to-stone ratio of the asphalt mixture with three different modifiers shows certain differences. AR-1 and AR-2 hardly change the optimal oil-to-stone ratio of the asphalt mixture, while AR-3 significantly increases it, indicating that the high-strength resin modifier has certain oil absorption properties.

Moreover, compared with the first two modifiers, The Marshall stability of the asphalt mixture with the addition of AR-3 modifier was increased by approximately 25%, demonstrating excellent high-temperature stability.

3.2 Indoor Road Performance Analysis

In this paper, dynamic stability rutting test (60°C, 0.7MPa and 70°C, 1.0MPa), low-temperature bending strain test (-10°C), water immersion residual stability and freeze-thaw splitting test were respectively adopted to evaluate the high-temperature stability, low-temperature cracking resistance and water stability of three asphalt mixtures. The forming process of the rutting plate specimen was carried out by using a wheel rolling forming machine to roll the specimen back and forth 12 times. The size of the specimen was 300mm×300mm×50mm. The test results are shown in Table 5.

Table 5. Test results of road performance.

Test item	AR-1	AR-2	AR-3	Specification
Dynamic stability(60°C, 0.7MPa), time/mm	17342	>20000	>20000	≥10000
Dynamic stability(70°C, 1.0MPa), time/mm	3607	5340	15108	≥6000
Residual stability after immersion, %	92.1	95.5	95.6	≥85
Freeze-thaw splitting strength ratio, %	82.3	85.7	93.1	≥80
Bending strain (-10°C), με	2551	2758	2906	≥2600

As can be seen from Table 5, under the test environment of 60°C and 0.7MPa, the dynamic stability of the three modified asphalt mixtures all exceeded 10,000 times /mm, demonstrating excellent high-temperature stability. However, when the test environment was raised to 70°C and 1.0MPa (i.e., high temperature and heavy load), the three modified asphalt mixtures showed significant performance differences. The anti-rutting ability of the first two modified asphalt mixtures was significantly reduced to less than 30%, while the AR-3 modifier still maintained a relatively high dynamic stability and showed lower temperature and pressure sensitivity. This plays a crucial role in the resistance of asphalt pavement to rutting disease in high-temperature and heavy-load sections. The reason lies in that AR-3 modifier is a high-molecular polymer material containing epoxy groups. It can form a strong chemical bond with the interface of SBS modified asphalt and stone materials, significantly enhancing the cohesion of asphalt mixtures, and thus having extremely excellent high-temperature stability. It is precisely for this reason that the residual stability and freeze-thaw splitting strength ratio indicators, which characterize the water stability performance of AR-3 modified asphalt mixture, are also significantly better than those of the previous two asphalt mixtures. In terms of low-temperature crack resistance, the low-temperature bending strain of AR-3 modified asphalt mixture is also superior to the previous two asphalt mixtures. The reason is that the oil absorption property of the AR-3 modifier leads to a higher optimal oil-to-stone ratio of the asphalt mixture, and the increase in asphalt content enhances the crack resistance of the mixture. Through experimental verification, AR-3 also has excellent road performance when used in the middle layer of 8cm thick SBS modified asphalt AC-25.

On the whole, the road performance of AR-3 modified asphalt mixture is the best, and it has a promising application prospect when used as the pavement material at the intersections of ordinary national and provincial trunk roads in high-temperature and rainy areas.

4 Project Effect Evaluation

The above-mentioned AR-3 modifier was directly added to the asphalt mixture through the mixing pot and applied to the upper and middle layers of the intersection treatment project of Provincial Road S218 in Jiangxi Province. One year after the opening of this section of road, on-site inspection was carried out through both manual and automated detection methods. The detection data of rutting depth is shown in Figure 4.

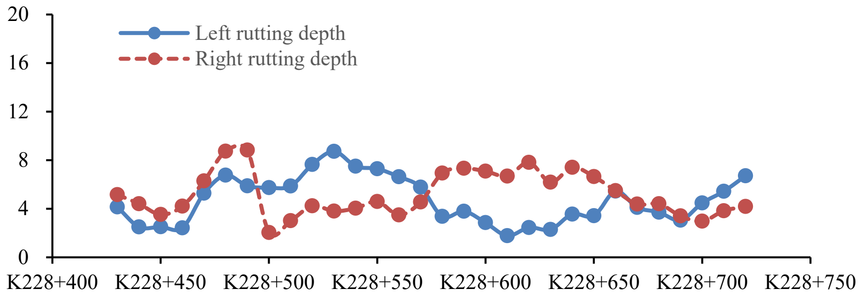

Fig. 4. The detection results of rutting depth on the construction section.

As can be seen from the above figure, the average representative rutting depth of the construction section one year after the opening to traffic is only 6.3mm, while the representative rutting depth of the section treated with the conventional treatment plan has exceeded 30mm one year after the opening to traffic. Therefore, the application of AR-3 modifier effectively reduces the rutting resistance of the intersection pavement, and there are no diseases such as cracking, scattering and particle dropping throughout the entire road section, demonstrating excellent comprehensive road performance.

5 Conclusions

In areas with high temperatures and abundant rainfall, intersections of ordinary national and provincial trunk roads are prone to diseases such as rutting, shifting and cracking due to the influence of low-speed vehicle travel, water release braking and frequent starts and stops. The results of the special pavement inspection show that the rutting disease of the asphalt pavement at the intersection is mainly caused by the compaction and wear of the upper layer and the flow of the middle layer, and does not involve structural rutting. The cracking disease is mainly caused by the fatigue damage of the surface layer material. The damage to cement pavement is caused by water damage, resulting in voids between the cement board and the upper base layer. Adding the polymer resin modifier (AR-3) to the asphalt mixture can significantly improve the high-temperature stability, low-temperature crack resistance and water stability of the asphalt mixture. The on-site test results of the physical project show that the average representative rutting depth of the construction section one year after the opening to traffic is only 6.3mm, and there are no diseases such as cracking, scattering and particle dropping. It demonstrates excellent comprehensive road performance and can effectively cope with the challenges brought by extreme high-temperature climates, heavy traffic and other environments to the asphalt pavement at intersections.

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