

Design method of the mix ratio of hot mix plant recycled asphalt mixture containing high mixture content

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Abstract. This paper mainly used the Superpave and the Marshall design methods to design the mix ratio of the hot mix plant recycled asphalt mixture. The road performance of AC-20, SUP-20 with 30% RAP content and AC-20 with 50% RAP content was studied to evaluate the water stability and high temperature stability and low temperature crack resistance of the recycled asphalt mixture. Research shows that the road performance of AC-20 mixed with 50% RAP content meets the technical requirements of the same type of asphalt mixture. It is recommended to use the Marshall design method for hot mix plant recycled asphalt mixture design.

1 Introduction

The hot mix in-plant recycling technology is currently the most commonly used pavement recycling technology at home and abroad. At present, the content of reclaimed asphalt mixture (RAP) is mostly controlled at 10%~30% [1-3]. With the rapid development of highway construction in China, many asphalt concrete pavements are in the period of medium and overhaul, and the waste asphalt mixture produced is increasing year by year [4,5]. Therefore, how to increase the proportion of RAP in recycled asphalt mixtures under the premise of meeting performance requirements is an important subject that scholars continue to explore. However, there are also many difficulties in the research process. For instance, compared with conventional hot mix asphalt mixtures, there are more variables involved in the design of recycled asphalt mixtures, and the content of new asphalt, new aggregates, RAP and the recycling agent should be taken into consideration. The conventional hot mix asphalt mixture design method has been unable to meet the needs of the mix design [6,7]. Therefore, it is of great significance to develop the optimization design of the mix ratio of the large content hot mix recycled asphalt mixture at a central plant.

2 Design specifications

This paper mainly used Superpave design method and Marshall design method to design the mix ratio of the hot mix plant recycled asphalt mixture. The content of this section mainly highlighted the selection of design indicators and the study of design methods. At the same time, on the basis of raw material tests, two design

methods were used to design the mix ratio for AC-20 and SUP-20 with different reclaimed asphalt mixtures. The results were compared for analysis.

Existing studies have shown that new asphalt has a reconciling effect on the reclaimed asphalt and can reduce the viscosity of the reclaimed asphalt. However, as the content amount of reclaimed asphalt added to the recycled asphalt mixture increases, the new asphalt may not be able to blend the recycled asphalt that meets the requirements of use. Considering the performance of the asphalt mixture, the content of reclaimed asphalt should not exceed 30%. When the amount exceeds this range, a suitable recycling agent should be selected to further restore the performance of the aged asphalt in the milling material. The selected recycling agent should be able to supplement the missing components of the reclaimed asphalt and feature good compatibility with the reclaimed asphalt. This project adopted self-developed SBS modified asphalt recycling agent to improve the performance of the reclaimed asphalt.

The key technical indexes of recycled asphalt are softening point, ductility, permeability and viscosity. All of these indicators must meet the Technical Specification for Asphalt Pavements on Highway (F40- (2004)). The details are shown in Table 1.

Table 1 Specification requirements for recycled asphalt (SBS modified asphalt)

Item	Penetration 25°C, 0.1mm	Softening point °C	Ductility (10°C), cm	135°C kinematic viscosity, Pa.s
Recycled asphalt	30-60	≥60	≥20	≤3

In order to ensure the performance of the recycled asphalt mixture so that it cannot be lower than the

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technical standard of conventional asphalt pavement, the design of the hot mix plant recycled asphalt mixture must meet the "Technical Specification for Construction of Highway Asphalt Pavements" (F40-2004), especially the volume and the performance standards. The details are shown in Table 2 and Table 3.

Table 2 Design specification requirements of AC-type hot mix in-plant recycled modified asphalt mixture

Testing item	AC-20
Striking times	75times per side
Stability (kN) no less than	8.0
FL (0.1mm)	20~40
VA (%)	4.0~6.0
Voids filled with asphalt (%)	65~75
Residual stability (%) not less than	85
Freeze-thaw split strength ratio (%) not less than	80
Dynamic stability (number of times/mm) not less than	2800

Note: 1. Conditional on the air void of the Marshall test pieces designed to be 3%, 4%, 5% and 6%, the voids in the mineral aggregate (VMA, %) of AC-25 mixture is 11, 12, 13, 14, respectively. When the design air void is less than an integer, use the interpolation method to determine the minimum VMA required. 2. Conditional on the air void of the Marshall test pieces designed to be 4%, 5% and 6%, the voids in the mineral aggregate (VMA, %) OF AC-20 mixture is 13, 14, 15 respectively. If the design air void is not an integer, use the interpolation method to determine the minimum VMA required.

Table 3 Design specification requirements for SUP-type hot mix plant recycled asphalt mixture

Testing item	SUP20
Compaction through rotation (number of rotation)	100
Degree of compaction per design time (%)	96
Degree of compaction in the beginning (%)	≤89
Degree of compaction of the end (%)	≤98
VMA (%)	≥13
VFA (%)	65 ~ 75
Filler-asphalt ratio (%)	0.6 ~ 1.2
Freeze-thaw split strength ratio (%) no less than	80
Dynamic stability (number of times/mm) no less than	2800

3 Design method

When it comes to the design method of the mix ratio of the hot mix in-plant recycled asphalt mixture, representative reclaimed asphalt mixture specimens need to be selected with corresponding properties identified. Also the aggregate gradation, asphalt content and asphalt viscosity at 60°C of the reclaimed asphalt mixture should be determined. In the meantime, the angularity of coarse and fine aggregates should be checked and new or reclaimed aggregates of proper particle sizes should be added to adjust the gradation defects. The AASHTO T202 method or T0625-2000 specified method can be used to test the viscosity of asphalt at 60°C, and based on which the content and grade of the fresh asphalt in the recycled asphalt mixture is determined. Or the content and grade of the fresh asphalt can be determined by testing the penetration of the reclaimed asphalt at 25°C.

4 Raw material test

This paper used diorite as the aggregate and SBS modified asphalt as the asphalt. The properties of raw materials are shown in Table 4-7:

Table 4 Aggregate density test results

Material particle size (mm)	Apparent relative density (g/cm ³)	Surface-dry relative density (g/cm ³)	Bulk volume density (g/cm ³)	Water absorption (%)
19	2.929	2.913	2.905	0.273
16	2.931	2.916	2.908	0.277
13.2	2.934	2.918	2.909	0.293
9.5	2.942	2.916	2.903	0.447
4.75	2.937	2.905	2.888	0.586
2.36	2.921	2.865	2.836	1.025
1.18	2.913	/	/	/
0.6	2.910	/	/	/
0.3	2.900	/	/	/
0.15	2.896	/	/	/
0.075	2.896	/	/	/
Mineral powder	2.763	/	/	/

Table 5 Asphalt density test results

Asphalt Type	Density (g/cm ³)
SBS modified asphalt	1.040

Table 6 Asphalt mixture extracting test results

	Asphalt - aggregate ratio (%)	The pass rate of the following sieve pore (%) (square hole sieve)										
		26.5	19.0	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Coarse RAP	2.1	100	98.2	91.8	76.8	24.8	10.1	8.5	7.1	5.4	3.8	3.1
Fine RAP	5.8	100	100	100	99.9	78.8	63.6	50.1	45.7	28.6	17.9	12.8

Table 7 Coarse and fine RAP aggregates improved density after extraction test results

Material specification	Coarse RAP		Fine RAP	
	≥4.75mm	<4.75mm	≥4.75mm	<4.75mm
Coarse and fine aggregate %	75.3	24.7	15.9	84.1
Bulk volume density (g/cm ³)	2.922	2.908	2.720	2.726

5 Asphalt mixture mix ratio design

5.1 AC-20 asphalt mixture gradation design (30% RAP)

The RAP content is 30%. According to the existing asphalt mixture mix ratio design method and process, the synthetic gradation is determined through the selection and testing of different gradations and contents of asphalt. As shown in Table 8, the best asphalt-aggregate ratio is determined as 4.4%. And the volume properties of the mixture are shown in Table 9.

Table 8 Designed gradation of AC-20 asphalt mixture

Gradation type	Quality performance (%) through the following sieve pores (square hole sieve, mm) (%)											
	26.5	19.0	16.0	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Designed gradation	100	95.2	89.8	76.5	60.2	44.8	26.5	19.4	15.2	10.1	7.6	4.7

Table 9 Asphalt mixture volume properties

Properties of the asphalt mixture	Designed results	Technical requirements
VA (%)	4.56	4.0~6.0
VMA (%)	13.64	≥13.48
VFA (%)	67.23	65~75
MS(kN)	16.25	≥8
FL(0.1mm)	27.3	15~40

Conditional on the best asphalt-aggregate ratio, the water damage resistance of the asphalt mixture was tested through the water immersion Marshall test and the freeze-thaw splitting test. At the same time, the rutting test and the low-temperature tests were carried out. The performance test results are shown in Table 10.

Table 10 Performance test results of AC-20 asphalt mixture

Test name	Water immersion Marshall test	Freeze-thaw splitting test	Rutting test	Low-temperature bending test
Test specification	Marshall residual stability S ₀ (%)	TSR (%)	Dynamic stability (number of times/m)	Failure strain (με)
Test result	90.2	85.8	4905	2763.0
Requirement (%)	≥85	≥80	≥2800	≥2500

It can be seen from Table 10 that the water stability, high temperature stability and low temperature crack resistance of the mixture all meet the requirements of the specification.

5.2 SUP20 asphalt mixture mix ratio design (30% RAP)

The RAP content is 30%. According to the indoor test, the determined design gradation of the asphalt mixture is shown in Table 11, and the results of the volume properties

of the mixture are shown in Table 12.

Table 11 SUP-20 Asphalt mixture designed gradation

Gradation type	Quality performance (%) through the following sieve pores (square hole sieve, mm) (%)										
	26.5	19.0	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Designed gradation	100	94.3	75.1	51.7	42.1	25.3	20.1	16.2	9.6	8.5	4.6

Table 12 SUP-20 asphalt mixture volume properties

Properties of the asphalt mixture	Design performance	Superpave standards
Air void VA (%)	3.98	4.0
VMA(%)	15.02	≥13
VFA(%)	70.89	65~75
Filler-asphalt ratio (%)	1.35	0.6~1.2*
Degree of compaction in the beginning (%)	83.9	≤89
Degree of compaction of the end (%)	97.5	≤98

Note: * means that when the coarse gradation is adopted, the filler-asphalt ratio can be increased to 0.8-1.6.

The gradation of this design is under the condition of the best asphalt-aggregate ratio. The water immersion Marshall test and the AASHTO T283 test were carried out to check the water damage resistance of the asphalt mixture. The rutting test and the low temperature tests were carried out at the same time. The test results are shown in Table 13.

Table 13 Performance test results of SUP-20 asphalt mixture

Test name	Water immersion Marshall test	Freeze-thaw splitting test	Rutting test	Beam bending test
Test specifications	Marshall residual stability S_0 (%)	TSR (%)	Dynamic stability (number of times/mm)	Failure strain ($\mu\epsilon$)
Test result	89.5	85.7	4134	2668.0
Requirement (%)	≥85	≥80	≥2800	≥2500

It can be seen from Table 13 that the water stability, high temperature stability and low temperature crack resistance of the mixture all meet the specification requirements.

The performance of the asphalt mixture designed by the Superpave design method and the Marshall design method all meets the specification requirements, and the performance of the AC-20 asphalt mixture designed by the

Marshall design method is slightly better than that of SUP20. With overall consideration, this paper recommends the use of Marshall design method for the design of hot mix in-plant recycled asphalt mixture.

5.3 AC-20 asphalt mixture gradation design (50% RAP)

When the use of RAP content is large, it is advisable to add a recycling agent during the design of the hot mix in-plant recycled asphalt mix ratio to restore the aged asphalt performance to a proper level to maximize the use of the reclaimed asphalt mixture so that the recycled HMA mixture has the best durability, ensuring that there is sufficient asphalt to coat the blank aggregate, and providing sufficient asphalt to meet the asphalt mixture design needs.

The RAP content used in this design is 50%, and the recycling agent SBS content is 5.8%. The mix ratio design referred to the design of recycled asphalt mixture with 30% RAP to determine the overall binding material content after the recycling agent is added. The results of the volume properties of the mixture are shown in Table 14.

Table 14 Volume Properties of Asphalt Mixture

Properties of the mixture	Design performance	Technical requirements
VA (%)	4.63	4.0~6.0
VMA (%)	14.38	≥13.48
VFA (%)	68.15	65~75
MS(kN)	15.78	≥8
FL(0.1mm)	26.1	15~40

The water immersion Marshall test, freeze-thaw splitting test, high temperature rutting and low temperature test were carried out. The performance test results are shown in Table 15.

Table 15 Performance test results of AC-20 asphalt mixture

Test name	Water immersion Marshall test	Freeze-thaw splitting test	Rutting test	Beam bending test
Test specifications	Marshall residual stability S_0 (%)	TSR (%)	Dynamic stability (number of times/mm)	Failure strain ($\mu\epsilon$)
Test result	88.6	85.1	4534	2675.0
Requirement (%)	≥ 85	≥ 80	≥ 2800	≥ 2500

It can be seen from Table 15 that the water stability, high temperature stability and low temperature crack resistance of the mixture all meet the requirements of the specifications. The performance is equivalent to that of asphalt mixture with 30% RAP, indicating that the modified SBS recycling agent can effectively improve the performance of the reclaimed asphalt mixture.

6 Conclusion

This paper used the Superpave design method and the Marshall design method to design the mix ratio of hot mix in-plant recycled asphalt with high RAP content. The research conclusions are as follows:

(1) The water stability, high temperature stability and low temperature crack resistance of AC-20 and SUP20 with 30% RAP were studied, and all the indicators meet the specification requirements, and the performance of the AC-20 asphalt mixture designed by Marshall design method is better than that of SUP20.

(2) The Marshall design method is recommended for the design of hot mix in-plant recycled asphalt mixture.

(3) The performance of AC-20 recycled asphalt mixture with high RAP content (50%) was analyzed. All performance indicators can also meet the technical requirements of asphalt mixture of the same type.

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