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Research on the Road Performance of Ring Diamond Resin Modified Asphalt Mixture

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Abstract: In order to solve the problems of ineffective modification and high cost of most asphalt modifiers, a new type of high viscosity and high elasticity asphalt modifier - ring diamond resin is introduced, and this modifier is injected into 70 # base asphalt. Through high-temperature rutting, low-temperature bending, immersion Marshall and freeze-thaw splitting tests, the road performance of 70 # base asphalt and ring diamond resin modified asphalt mixture is compared and analyzed. Intended to improve the quality of asphalt pavement while reducing economic costs, thereby extending the service life of the road. The research results indicate that the ring diamond resin modifier can greatly improve the high-temperature performance of asphalt mixtures, and to a certain extent improve their low-temperature crack resistance and water stability. It is a resin modified material with great potential and high advantages. It is recommended to use a dosage of 1% in practical road engineering applications.

Keywords: Ring Diamond Resin; Modified Asphalt; Road Performance.

1. Introduction

With the continuous improvement of people's living standards, the requirements for road driving safety and comfort are also increasing. Asphalt pavement is widely used in high-grade highways in China due to its comfortable driving, good performance, simple maintenance, short construction time, and convenient post maintenance. However, due to the insufficient performance of traditional matrix petroleum asphalt, various pavement diseases often occur on asphalt pavements that are built and opened to traffic, greatly limiting the performance of the pavement[1]and leading to a decrease in its service life[2]. Therefore, it is necessary to improve traditional road petroleum asphalt[3-4]. At present, adding modifiers to traditional petroleum asphalt is the main improvement method[5-6], among which resin based modifiers are the most researched and widely used improvement method[7-8].

We are currently studying a new type of high viscosity and high elasticity resin based asphalt modifier - ring diamond resin, as a modifier for 70 # base asphalt, and forming ring diamond resin modified asphalt under certain preparation processes. By conducting tests such as high-temperature rutting, low-temperature bending, freeze-thaw splitting, and immersion Marshall, a comparative study was conducted on the road performance of 70 # matrix asphalt and ring diamond resin modified asphalt mixture, revealing their practical performance in road surfaces.

2. Experimental Raw Materials

2.1. Ring Diamond Resin

We have selected the ring diamond resin modifier provided by Jialunke Petrochemical Technology Jiangsu Co., Ltd., which is a new type of high viscosity and high elasticity petroleum resin modified asphalt mixture material synthesized through special processes using high molecular weight polymers. The appearance of ring diamond resin is yellow granular, as shown in Figure 1. It belongs to the thermoplastic resin type modifier, and its performance indicators are shown in Table 1.

Figure 1. Ring diamond resin

Table 1. Performance indicators of ring diamond resin

Indicator items	unit	numerical value
density	g/cm^3	0.923
Shore hardness	-	D/1:55
Melt index	g/10min	1.57
tensile strength	MPa	13.6
elongation at break	%	512
bending strength	MPa	8.60
Bending modulus	MPa	229
Injection temperature	℃	210

2.2. Asphalt

The 70 # road petroleum matrix asphalt provided by Jialunke Petrochemical Technology Jiangsu Co., Ltd. was selected, and its performance indicators are shown in Table 2. All indicators meet the requirements of the "Test Specification for Asphalt and Asphalt Mixtures in Highway Engineering" (JTGE20-2011).

2.3. Aggregates

The mineral aggregates in asphalt mixtures can be divided into three categories based on their different particle sizes, namely coarse aggregates, fine aggregates, and mineral fillers.

Table 2. 70#Performance indicators of road petroleum asphalt

Test indicators		Regulatory requirements	test result	test method
Needle penetration(0.1mm)		60~80	62	T0604
softening point(℃)		≥46	51.3	T0606
Elongation(cm)		≥100	137.2	T0605
dynamic viscosity(Pa·s)		≥180	218	T0620
flash point(℃)		≥260	276	T0611
solubility(%)		≥99.5	99.78	T0607
After TFOT	Quality changes(%)	≤±0.8	0.16	T0609
	Residual penetration ratio(%)	≥61	71.3	T0604
	Residual ductility(%)	≥6	8.5	T0605

Coarse aggregate generally refers to stone with a particle size exceeding 2.36mm, while fine aggregate refers to stone with a particle size between 0.075 and 2.36mm. Mineral fillers are usually defined as powdered minerals with a particle size less than 0.075mm, also known as mineral powder. The coarse and fine aggregates are selected from high-quality diabase provided by the Jingli Expressway Project Department, while the mineral powder is limestone. According to relevant specifications, coarse aggregate, fine aggregate, and mineral powder have been tested through material performance tests [5]. The test results are shown in Tables 3-5, and all indicators meet the requirements of the "Test Specification for Asphalt and Asphalt Mixtures in Highway Engineering" (JTGE20-2011).

Table 3. Basic performance indicators of coarse aggregate

Test items	unit	Regulatory requirements	Actual measurement results	test method
Apparent relative density	g/cm^3	-	2.943	T0304
Dry relative density	g/cm^3	-	2.897	T0304
Gross bulk density	g/cm^3	-	2.873	T0304
Crushing value of stone materials	%	≤26	16.8	T0316
Content of needle shaped particles	%	≤15	10.1	T0312
Los Angeles wear loss	%	≤28	13.6	T0317
Water absorption rate	%	≤2.0	0.7	T0304
Mud content	%	≤1	0.5	T0310
<0.075 particle content	%	≤1	0.4	T0310

Table 4. Basic performance indicators of fine aggregate

Test items	unit	Regulatory requirements	Actual measurement results	test method
Apparent relative density	g/cm^3	-	2.664	T0328
Sand equivalent	%	≥60	72	T0334
Durability (content>0.3mm)	%	≥12	14.7	T0340
Mud content (<0.075mm content)	%	≤3	1.5	T0333

Table 5. Basic performance indicators of mineral powder

Test items	unit	Regulatory requirements	Actual measurement results	test method
Apparent relative density	g/cm^3	-	2.71	T0352
water content	%	≤1	0.3	T0103
Hydrophilicity coefficient	%	≤1	0.65	T0353
Plasticity index	%	≤4	2.8	T0354

2.4. Mix Proportion Design

Using AC-13 continuous grading as the design grading, and taking into account factors such as transportation and climate in the southern region, a new type of composite grading slightly lower than the median grading is designed. The gradation design of mineral materials is shown in Table 6, and the gradation curve is shown in Figure 2..

Table 6. AC-13 aggregate grading design

Sieve size(mm)	Sieve pass rate (%)									
	16.0	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Upper limit of gradation	100	100	85	68	50	38	28	20	15	8
Median grading	100	95	76	53	37	26	19	13	10	6
Composite gradation	100	93.6	70.6	40.7	26.8	19.7	14.3	11.2	9.5	5.3
Lower limit of gradation	100	90	68	38	24	15	10	7	5	4

2.5. Best Oil to Stone Ratio

Referring to the Marshall test plan in the "Test Specification for Asphalt and Asphalt Mixtures in Highway Engineering" (JTGE20-2011), with a 4% oil stone ratio as the initial value and an interval of 0.5 percentage points, five different oil stone ratios were designed. Six indicators, including stability, gross volume density, porosity, asphalt saturation, mineral porosity, and flow value, were measured for different Marshall specimens, and the trend of each indicator with the change of oil stone ratio was plotted as shown in Figures 3-8.

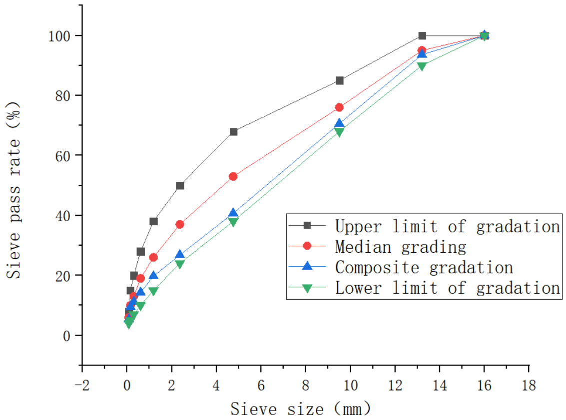

Figure 2. AC-13 Grading Curve

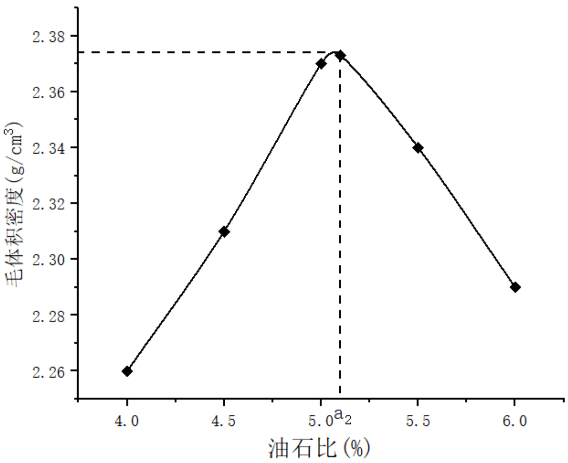

Figure 3. Gross bulk density

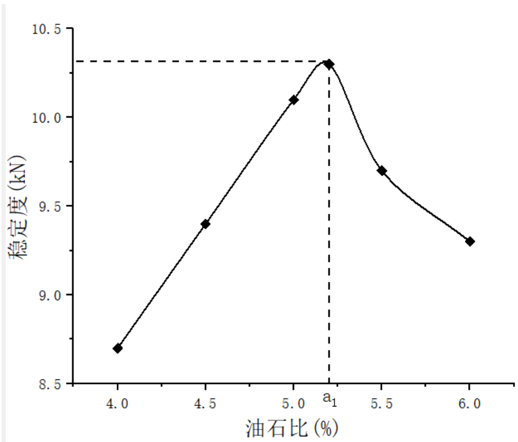

Figure 4. Stability

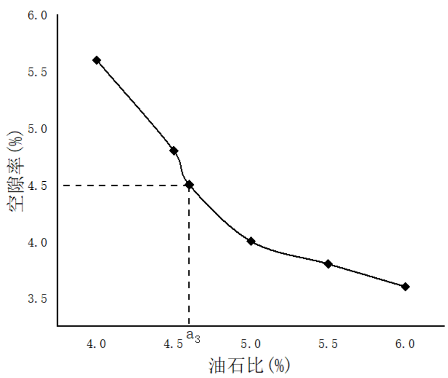

Figure 5. Void rate

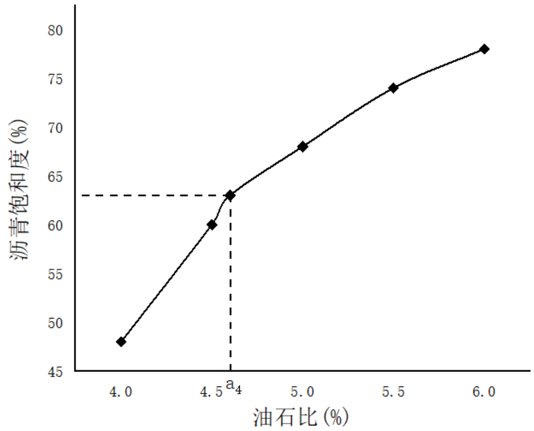

Figure 6. Asphalt saturation

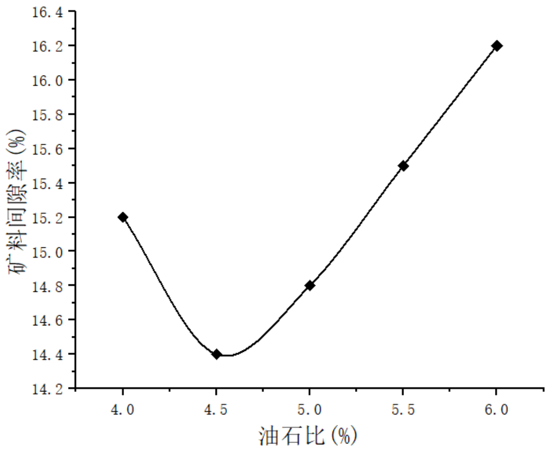

Figure 7. Mineral clearance rate

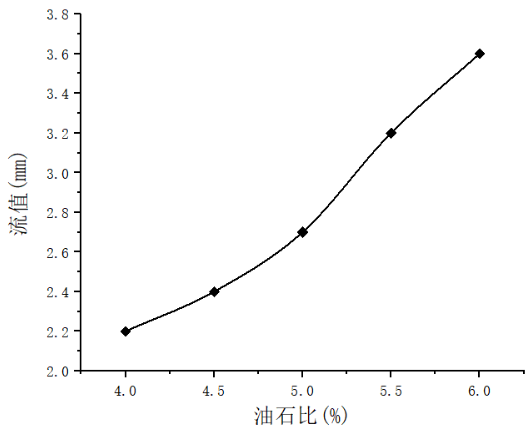

Figure 8. Flow value

Based on the curve of the variation of the above indicators with the oil to stone ratio, it can be concluded that, A1 is the oil stone ratio of 5.1% corresponding to the maximum gross volume density, A2 is the oil stone ratio corresponding to the maximum gross volume density of 5.2%, When a3 is the median porosity, the corresponding oil stone ratio is 4.6%, When a4 is the median saturation of asphalt, the corresponding oil to stone ratio is 4.6%, while OAC2 is the median of the asphalt dosage range OACmin~OACmax that meets the technical standards for all indicators.

$$OAC_1 = \frac{a_1 + a_2 + a_3 + a_4}{4} = 4.875\%$$

$$OAC_2 = \frac{OAC_{\max} + OAC_{\min}}{2} = \frac{5.42\% + 4.52\%}{2} = 4.97\%$$

$$OAC = \frac{OAC_1 + OAC_2}{2} = \frac{4.875\% + 4.97\%}{2} = 4.92\%$$

Therefore, based on the above formula, the optimal oil to stone ratio is determined to be 4.92%.

3. Sample Preparation and Testing Plan

3.1. Sample Preparation

Due to the fact that the ring diamond resin modifier belongs to thermoplastic resin modified materials, it is prone to agglomeration when mixed with the matrix asphalt in a high-temperature molten state. Therefore, in the preparation process, it should be distributed as evenly as possible. The specific preparation process mainly includes the following steps:

(1) Heat the 70 # base asphalt into a 130 ℃ oven until it is in a molten state;

(2) Weigh a certain amount of matrix asphalt and pour it into a pre prepared enamel cup. Place it on an electronic furnace lined with asbestos mesh and continue heating;

(3) Weigh a certain amount of ring diamond resin and pour it into an enamel cup filled with base asphalt. Add it while stirring with a glass rod to make it preliminary mixed;

(4) Put the rotary head of the shear into the asphalt, adjust it to the appropriate height, turn on the switch, and shear for 1h at the speed of 4000r/min, during which the shear temperature shall be kept at about 160 ℃.

Figure 9. Preparation of modified asphalt samples using ring diamond resin

(5) After cutting, place it in an oven at 160 ℃ and heat it for 1 hour to fully blend it;

(6) Weigh the corresponding mass of ring diamond resin and repeat the above steps to prepare ring diamond resin modified asphalt with dosages of 1%, 3%, 6%, 9%, and 12%, respectively.

The ring diamond resin modified asphalt sample prepared through the above steps is shown in Figure 9.

3.2. Experimental Plan

To verify the road performance of modified asphalt mixture with ring diamond resin, the 70 # matrix asphalt and four different preparation processes of asphalt mixture samples are grouped and numbered according to Table 7.

Table 7. Experimental grouping

Group number	Remarks
A	70 # Matrix asphalt group
B	Ring diamond resin modified asphalt group prepared by wet process according to the median gradation
C	Ring diamond resin modified asphalt group prepared by dry process according to the median gradation
D	Ring diamond resin modified asphalt group prepared by synthetic gradation and wet process
E	Ring diamond resin modified asphalt group prepared by synthetic gradation and dry process

According to Table 7, five different asphalt mixture sample groups with numbered numbers were compared for high-temperature rutting test, low-temperature bending test, immersion Marshall test, and freeze-thaw splitting test. Among them, the high-temperature rutting test uses dynamic stability to evaluate the high-temperature performance of each group, and the low-temperature bending test uses average failure strain to evaluate the low-temperature crack resistance performance of each group. Through immersion Marshall test and freeze-thaw splitting test, the residual stability of immersion and the freeze-thaw splitting strength ratio are calculated separately, and then the water stability is comprehensively evaluated.

4. Performance Testing of Asphalt Mixtures for Road Use

4.1. High Temperature Stability Research

As shown in Table 8, The dynamic stability of Group A is only 1266 times/mm, The dynamic stability of Group B is 6264 beats/mm, The dynamic stability of Group C is 6472 beats/mm, The dynamic stability of Group D is 7528 beats/mm, The dynamic stability of Group E is 8215 times/mm, and each group meets its specification requirements. Among them, the dynamic stability of Group E is the highest, with a value far greater than the dynamic stability of 70 # base asphalt and the required dynamic stability in the specifications (2800 times/mm). It can be seen from this that the ring diamond resin modifier can greatly improve the high-temperature stability of asphalt.

Due to the different preparation processes of each group, the dynamic stability values generated are also different. By comparing the dynamic stability of asphalt mixtures under different conditions, it can be found that the dynamic stability of Group C and Group E is greater than that of Group B and Group D. This indicates that under the same gradation, the high-temperature performance of the ring diamond resin modified asphalt prepared by dry method is better; Compare Group B with Group D In groups C and E, it can be observed that the dynamic stability of groups D and E is greater than that of groups B and C, indicating that under the same preparation process, the high-temperature performance of the synthesized graded ring diamond resin modified asphalt is better than that of the ring diamond resin modified asphalt made from the median gradation. In summary, the high-temperature performance of ring diamond resin modified asphalt prepared by dry method and synthetic grade slightly lower than the median AC-13 gradation is the most excellent.

Table 8. High temperature rutting test results of asphalt mixture

Asphalt mixture type	d_1(mm)	d_2(mm)	DS (once/mm)	Specification requirements (times/mm)
Group A	10.278	12.660	1266	≥1000
Group B	2.006	2.110	6264	≥2800
Group C	1.839	1.937	6472	
Group D	1.497	1.581	7528	
Group E	1.096	1.161	8215	

4.2. Low Temperature Stability Research

As shown in Table 9, The failure strain of Group A is 2260.33, The failure strain of Group B is 2535.83, The failure strain of Group C is 2639.91, The failure strain of Group D is 3148.72, while Group E has the highest failure strain value, which is 3335.26. From this, it can be seen that the ring diamond resin modifier can improve the low-temperature performance of the matrix asphalt to a certain extent.

Due to the different preparation processes of each group, the resulting failure strain values are also different. By comparing the failure strains of asphalt mixtures under different conditions, it can be found that the failure strain values of Group C and Group E are both greater than those of Group B and Group D. This indicates that under the same gradation, the low-temperature crack resistance performance of ring diamond resin modified asphalt prepared by dry method is better than that prepared by wet method; And compared with Group B and Group D It can be observed that the failure strain values of Group D and Group E are both greater than those of Group B and Group E. Under the same preparation process, the low-temperature performance of the synthesized graded ring diamond resin modified asphalt is better than that of the ring diamond resin modified asphalt made with the median gradation. From this, it can be concluded that the low-temperature crack resistance performance of the modified asphalt with ring diamond resin prepared by dry method and synthetic grade slightly lower than the median AC-13 gradation is the most excellent.

Table 9. Low temperature bending test results of asphalt mixture

Asphalt mixture type	Bending and tensile strength (MPa)	Destructive strain($\mu\varepsilon$)	Stiffness modulus(MPa)	Failure strain specification requirement($\mu\varepsilon$)
Group A	7.61	2260.33	3361.29	≥2000
Group B	8.05	2535.83	3457.19	≥2500
Group C	8.20	2639.91	3676.34	
Group D	9.88	3148.72	4168.32	
Group E	11.18	3335.26	4242.70	

4.3. Water Stability Research

4.3.1. Immersion Marshall Test

As shown in Table 10, The residual stability of Group A after immersion in water is 86.2%, The residual stability of Group B after immersion in water is 87.3%, The residual stability of Group C after immersion in water is 88.2%, The residual stability of group D after immersion in water is 91.7%, The residual stability of E group after immersion is 92.6%, and all indicators of each group meet the standard requirements. Among them, The immersion residual stability of Group A is the minimum value, while the immersion residual stability of Group E is the maximum value, which is 7.4% higher than Group A. It can be seen that the ring diamond resin modifier can improve the water stability of asphalt.

Due to the different preparation processes of each group, the residual stability of the immersed asphalt produced varies. By comparing the residual stability of the immersed asphalt mixture under different conditions, it can be found that the MS0 of Group C and Group E is greater than that of Group B and Group D. This indicates that under the same gradation, the water stability of the ring diamond resin modified asphalt prepared by dry method is better than that prepared by wet method; And compared with Group B and Group D It can be observed that the MS0 of groups C and E is slightly higher than that of groups B and E. Under the same preparation process, the water stability of the synthesized graded ring diamond resin modified asphalt is better than that of the ring diamond resin modified asphalt made with the median gradation. Therefore, it can be concluded that the water stability performance of modified asphalt with ring diamond resin prepared by dry method and synthetic grade slightly lower than the median AC-13 gradation is the most excellent.

On the other hand, the flow value of asphalt mixture refers to the vertical deformation of the Marshall specimen when it reaches the failure point under compression. The smaller the value, the smaller the deformation generated by the asphalt mixture when it is damaged, indicating better water stability performance. As shown in Table 5.7, The flow value of Group A is 2.85mm, The flow value of Group B is 2.68mm, The flow value of Group C is 2.63mm, The flow value of Group D is 2.47mm, The flow value of Group E is 2.36mm, and the order of flow values from small to large is: Group E<Group D<Group C<Group B<Group A. Among them, A has the highest flow value, while Group E has the lowest flow value, and both meet the specification requirements (flow value range: 1.5mm~4.5mm). Therefore, it can also be concluded that the ring diamond resin modifier has a certain improvement in the water stability performance of the matrix asphalt, and the water stability performance of the ring diamond resin modified asphalt prepared by dry method and synthetic grade slightly lower than the AC-13 grading median is the most excellent.

Table 10. Marshall test results of asphalt mixture immersion

Asphalt mixture type	MS (kN)	MS_1 (kN)	MS_0 (%)	Flow value (mm)	MS_0 specification Requirement (%)
Group A	10.33	8.90	86.2	2.85	≥80
Group B	10.89	9.51	87.3	2.68	≥85
Group C	11.12	9.81	88.2	2.63	
Group D	12.24	11.22	91.7	2.47	
Group E	12.88	11.93	92.6	2.36	

4.3.2. Freeze-thaw Splitting Test

As shown in Table 11, The strength ratio of freeze-thaw splitting test in Group A is 77%, The strength ratio of freeze-thaw splitting test in Group B is 86.8%, The strength ratio of freeze-thaw splitting test in Group A is 88.6%, The strength ratio of freeze-thaw splitting test in Group A is 90.1%, The strength ratio of freeze-thaw splitting test in Group A is 92.3%, and all indicators meet the specification requirements. Among them, The freeze-thaw splitting test strength ratio of Group A is the smallest, while the freeze-thaw splitting test strength ratio of Group E is the largest, 19.9% higher than Group A. It can be seen that the ring diamond resin modifier can improve the water stability of the base asphalt.

Due to the different preparation processes of each group, the freeze-thaw splitting test strength ratios produced are also different. Now, by comparing the freeze-thaw splitting test strength ratios of asphalt mixtures under different conditions, it can be found that the freeze-thaw splitting strength ratios of Group C and Group E are greater than those of Group B and Group D. This indicates that under the same gradation, the water stability of ring diamond resin modified asphalt prepared by dry method is better than that of ring diamond resin modified asphalt prepared by wet method; And compared with Group B and Group D It can be observed that the freeze-thaw splitting strength ratio of Group D and Group E is slightly higher than that of Group B and Group E, indicating that under the same preparation process, the water stability performance of the synthesized graded ring diamond resin modified asphalt is better than that of the ring diamond resin modified asphalt made with the median gradation. Therefore, it can be concluded that the water stability performance of modified asphalt with ring diamond resin prepared by dry method and synthetic grade slightly lower than the median AC-13 gradation is the most excellent.

Table 11. Results of freeze-thaw splitting test for asphalt mixture

Asphalt mixture type	R_{T1} (MPa)	R_{T2} (MPa)	TSR (%)	TSR specification requirements (%)
Group A	0.924	0.712	77.0	≥75
Group B	0.940	0.816	86.8	≥80
Group C	1.015	0.900	88.6	
Group D	1.067	0.960	90.1	
Group E	1.082	0.999	92.3	

5. Conclusion

This article comprehensively analyzes the road performance of ring diamond resin modified asphalt mixture from three aspects: high temperature performance, low temperature performance, and water stability performance. The following conclusions are drawn:

(1) Through high-temperature rutting tests, it can be found that the ring diamond resin modifier greatly improves the high-temperature performance of 70 # base asphalt, and the high-temperature performance of E group asphalt mixture is the most excellent.

(2) Through low-temperature bending tests, it has been proven that the ring diamond resin modifier can improve the low-temperature crack resistance of 70 # base asphalt to a certain extent, and the low-temperature performance of E group asphalt mixture is the most excellent.

(3) Through the immersion Marshall test and freeze-thaw splitting test, it was found that the ring diamond resin modifier can improve the water damage resistance of 70 # base asphalt to a certain extent, and the water stability performance of E group asphalt mixture is the most excellent.

In summary, the high temperature performance, low temperature performance, and water stability of the modified asphalt mixture with ring diamond resin are better than those of the base asphalt, especially the most obvious improvement effect on high temperature performance. It can be seen that ring diamond resin is a good high viscosity and high elasticity modified material, and the road performance of ring diamond resin modified asphalt mixture prepared by dry method and synthetic grade slightly lower than the AC-13 grading median is the best. It is recommended to use ring diamond resin modifier with a dosage of 1% for practical pavement engineering.

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