

Analysis of factors affecting water stability of foam warm mix asphalt mixture

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Abstract: water stability of warm mix asphalt mixture based on foamed asphalt is the key evaluation index affecting its road performance. The moisture content in the production process of foamed asphalt is unfavorable to the water stability of warm mix asphalt mixture. In order to improve its water stability, through immersion Marshall test and freeze-thaw splitting test, taking foaming effect, asphalt temperature, foaming water consumption and polymer fiber content as influencing factors, the control variable method is used to study and analyze the influence of factors on the water stability of warm mix asphalt mixture. The test results show that the foaming effect of asphalt, asphalt temperature, foaming water consumption and fiber content are the direct factors affecting the water stability of warm mix asphalt mixture. According to the importance analysis of random forest variables, foaming water consumption, foaming effect and asphalt temperature are the most important variables, while fiber content is the least. Taking the asphalt used in this paper as an example, it is suggested to improve the water stability of warm mix asphalt mixture with the combination of the best foaming effect, asphalt temperature 155 °C, foaming water consumption 2% and fiber content 0.3%.

1 Introduction

Compared with hot mix asphalt mixture, warm mix asphalt mixture has the advantages of saving resource consumption and reducing environmental pollution; compared with cold mix asphalt mixture, warm mix asphalt mixture can significantly improve pavement performance. In view of the technical advantages of warm mix asphalt mixture, warm mix technology has been applied in a large number of pavement engineering at home and abroad [1-4]. Warm mix technology can be divided into three types: emulsification, organic additives and foamed asphalt. Emulsification and organic additives need to add warm mixing agent to realize warm mixing process, and the representative product is Evotherm™, Sasobit® and asphaltan B®. Etc. Foam asphalt warm mixing technology is to achieve the purpose of viscosity reduction by using foam asphalt, so as to achieve warm mix asphalt mixture. The warm mix process based on foamed asphalt does not need to add additives. It is completely physical reaction, low cost and mature technology. It has obvious advantages in preparing warm mix asphalt mixture. Because of the need of water for asphalt foaming, the water stability of foam warm mix asphalt is the key to the durability and mechanical properties of the mixture. The influence factors of foam warm mix asphalt are more. Asphalt temperature, asphalt foaming effect, foaming water consumption, mixing temperature and additive type all have different degrees of water stability of warm mix asphalt mixture. influence.

At present, road researchers at home and abroad have carried out a lot of research on the water stability of warm mix asphalt mixture. Wang Fu [5] used Sasobit LM and Honeywell titantm to prepare warm mix asphalt mixture, and studied the correlation between anti loose performance and water stability of warm mix asphalt mixture. Mao Cheng [6] evaluated the water stability of original asphalt and warm mix asphalt mixture based on immersion Marshall test and freeze-thaw splitting test. Huang Chuan [7] used orthogonal test to evaluate the influence of rap content, warm mix agent content, mixture particle size and other factors on the water stability of warm mix recycled asphalt mixture. In order to improve the water stability of foam warm mix asphalt, the influence of foaming effect, foaming water consumption, asphalt temperature and fiber dosage on the water stability of warm mix asphalt mixture was studied and analyzed. Residual stability and freeze-thaw splitting tensile strength ratio were used to evaluate the water stability of the mixture, so as to provide feasible technology for the study of water stability of warm mix asphalt mixture. support.

2 Test materials

2.1 Aggregate

The aggregate used in this experiment is diabase, and the technical indicators of the aggregate are shown in Table 1.

Table 1 Summary of aggregate performance test results

Project	Test Results	Technical Index Requirements
Crushing value/%	22	≤26
Los Angeles abrasion value/%	19	≤28
Stone polishing value/BPN /BPN	45	≥42
Coarse aggregate solidity/%	8	≤12
Coarse aggregate needle flake content/%	9	≤15
Sand equivalent/%	55	≤65

its technical indicators are shown in Table 2.

2.2 Asphalt foaming characteristics

CNOOC Binzhou 70# asphalt was used in the test, and

Table 2 Asphalt technical index test results

Index	Unit	Measured value	Technical requirement	Test method
Penetration (25°C、100g、5s)	0.1mm	74.8	60~100	T0604
Softening point (TR&B)	°C	60.2	≥46	T0606
Ductility (15°C、5cm/min)	cm	>100	≥100	T0605
Wax content (distillation method)	%	1.7	<2.2	T0615
Flash point	°C	257	≥260	T0611
Solubility	%	99.97	≥99.5	T0607
Density (15°C)	g/cm3	1.065	Measured	T0603
RTFOT Residues after				
Mass change, not more than	%	-0.15	±0.8	T0610
Residual penetration ratio (25°C)	%	69	≥61	T0604
Residual ductility (10°C)	cm	8.4	≥6	T0605

This test is based on Wirtgen WLB10 asphalt foaming machine for asphalt foaming test. CNOOC Binzhou 70# asphalt is used as foamed asphalt. The foamed asphalt is generated by changing the asphalt temperature and foaming water consumption and other

influencing factors. The different effects of asphalt are tested. Factors of expansion rate and half-life index, comprehensive evaluation of the foaming effect of asphalt. As shown in the table below.

Table 3 Asphalt foaming test results

Asphalt type	Asphalt temperature (°C)	Water consumption for foaming (%)	Average expansion ratio	Average half-life (s)
CNOOC Binzhou 70# Asphalt	135	2	9	46.6
		3	11	43.2
		4	12	40.4
	140	2	11	37.5
		3	12.6	35.0
		4	14.4	32.8
	145	2	14	28.8
		3	16.2	25.9
		4	20	22
150	2	19	29	

		3	21.5	27.4
		4	24	26
		2	25	27.3
155		3	26.7	26
		4	29	25
		2	26.1	18
160		3	27.0	16.5
		4	27.5	15
		2	27.8	15
165		3	28.2	15
		4	29	14

It can be seen from the data in Table 1-3 above that the foaming temperature range of CNOOC Binzhou 70# asphalt is set at 135 ~ 165 °C, the foaming water consumption range is 2%~4%, the measured half-life and expansion ratio data, the half-life range is 14~46.6s, the expansion ratio range is 9~29 times. From the expansion ratio and half-life data, it can be seen that the expansion ratio increases with the increase of the foaming water consumption, and the half-life decreases with the increase of the foaming water consumption. In general, CNOOC Binzhou 70# asphalt has excellent foaming effect and meets the foaming requirements of the cold recycling specification [8] (expansion ratio ≥ 10 times, half-life ≥ 8s). In order to facilitate the analysis

of the impact of the foaming effect in the later stage, this article refers to the previous research experience [9], comprehensively weighs the asphalt expansion ratio and half-life data at different temperatures, and divides the asphalt foaming effect into three levels: excellent (expansion ratio approximately 26.7 times, half-life of about 26s), good (expansion ratio of about 28.2 times, half-life of about 15s), medium (expansion ratio of about 11 times, half-life of about 43.2s)

2.3 Fiber

See Table 4 for technical indicators of polypropylene impermeable short fiber.

Table 4 Main performance indicators of fiber

Item	Linear density (g/cm ³)	Melting point (°C)	Elastic modulus (MPa)	Moisture absorption rate (%)	Tensile strength (MPa)	Ignition point (°C)
Index	0.91	160~180	3850	< 0.1	600	590

This test uses GAC-20 type gradation, and the mixture gradation is shown in Table 5.

3 Experimental design

3.1 Grading design

Table 5 Asphalt Mixture Grading Design

Screen size/mm	19	16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Pass rate/%	97.5	83.4	72.6	64.5	37.7	24.5	15.6	13.4	9.4	6.6	5.8

3.2 Optimum mixing temperature

The mixing temperature is a key factor for the control of asphalt mixture construction [10]. In this test, the porosity of warm-mix asphalt mixtures and hot-mix

asphalt mixtures at different mixing temperatures is tested to determine the mixing temperature of the warm-mix asphalt mixtures. As shown in Figure 1 below.

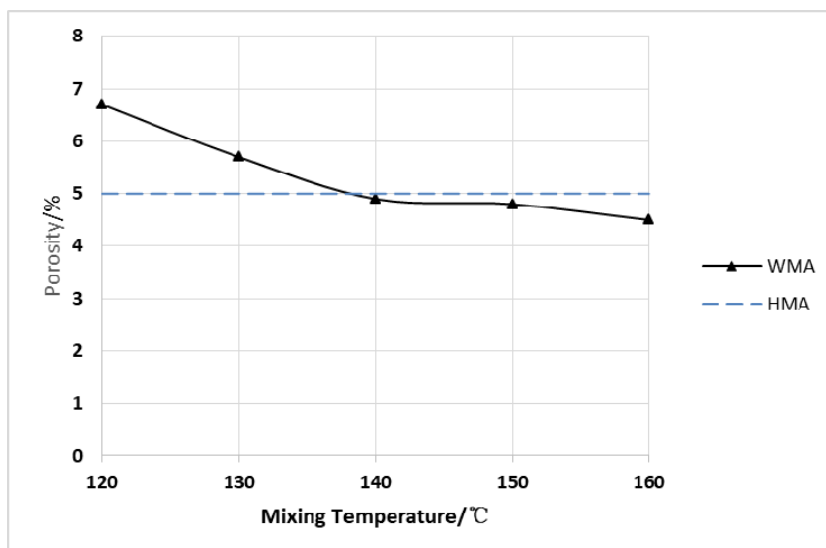


Figure 1 The relationship curve between mixing temperature and porosity

The analysis of the curve in Figure 1 shows that with the increase of mixing temperature, the porosity of the warm-mix asphalt mixture sample shows a decreasing trend. When the mixing temperature is 160°C, the voids of the warm-mix asphalt mixture The rate is 4.5%, reaching the lowest value, in other words, reaching the maximum degree of compaction; when the mixing temperature is 120~140°C, the porosity decays greatly, indicating that the compaction of the warm-mix asphalt mixture is insufficient under low temperature conditions. , The temperature rise can effectively improve the compaction of the mixture; when the mixing temperature is 140~160°C, the porosity attenuation is smaller, indicating that when the mixing temperature exceeds 140°C, the compactness of the warm-mix asphalt mixture reaches At a certain level, the continued increase in temperature has little effect on the degree of compaction. When the mixing temperature is 140°C, the void ratio of the warm-mix asphalt mixture is very close to that of the hot-mix asphalt mixture. As shown in the figure, combined with the porosity of the hot-mix asphalt mixture of 5.0%, it indicates that when the mixing temperature exceeds 140°C, the compaction of the warm-mix asphalt mixture exceeds that of the hot-mix asphalt mixture, and the compactness reaches the hot-mix asphalt mixture. Level. Therefore, this article sets the mixing temperature of warm-mix asphalt mixture

to 140°C.

3.3 Experimental design

The water stability of foamed warm-mix asphalt mixture is the key to determining durability. In this paper, the factors that affect its water stability (asphalt temperature, foaming water consumption, and polymer fiber content) are explored to explore the possibility of improving water stability. Operational methods. The asphalt foaming effect is divided into three levels: A, B, C; the asphalt temperature is divided into 135°C, 145°C, 155°C, 165°C; the foaming water consumption is divided into 2%, 2.5%, 3%, 3.5% , 4%; fiber content is divided into 0.0%, 0.2%, 0.4%, 0.6%. As shown in Table 6.

Existing studies have shown that there are many influencing factors on the water stability of warm-mix asphalt mixtures, and the influencing factors often interact with each other. Therefore, in order to study the influence of related factors on water stability, this paper adopts the method of controlling a single variable. Under the premise of controlling other variables, explore the influence of a single factor on the water stability of the warm-mix asphalt mixture. Then analyze the relative importance of influencing factors based on the random forest algorithm [11].

Table 6 Experimental Design

Level \ factor	Asphalt foaming effect	Asphalt temperature (°C)	Water consumption for foaming (%)	Fiber content (%)
1	A	135	2.0	0.0
2	B	145	2.5	0.2
3	C	155	3.0	0.4
4	—	165	3.5	0.6
5	—	—	4	—

4 test analysis

4.1 Influence of foaming effect

Asphalt foaming effect is the key factor of the asphalt film forming effect of the warm-mix asphalt mixture, and also the key factor of the asphalt dispersion effect of the cold-mix asphalt mixture. The foaming effect of asphalt is mainly reflected by the expansion ratio and half-life.

The foaming effect of asphalt is mainly determined by the foaming conditions (bitumen temperature and foaming water consumption). Therefore, this article comprehensively measures the expansion ratio and half-life, and sets the asphalt foaming effect to three levels, as shown in the following table. In order to analyze the influence of a single factor in the foaming effect, the foaming water and fiber content of the asphalt were controlled, and only the temperature of the asphalt was adjusted to control the foaming effect.

Table 7 Asphalt foaming effect and foaming conditions

Horizontal	foaming effect		foaming condition	
	Expansion ratio	Half-life/s	Asphalt temperature/°C	Water addition for foaming/%
A	26.7	26	155	3
B	28.2	15	165	3
C	11	43.2	135	3

Table 8 Test results of immersion Marshall and freeze-thaw splitting

Foaming effect	A	B	C	Hot mix
Stability/KN (immersed in water for 30min)	10.00	10.59	11.68	11.88
Stability/KN (soaked in water for 48h)	9.62	9.74	9.58	11.52
Residual stability (%)	0.96	0.92	0.82	0.97
Splitting tensile strength before freezing (MPa)	1.42	1.19	1.21	1.48
Splitting tensile strength after freezing and thawing (MPa)	1.31	1.00	0.97	1.39
Freeze-thaw splitting tensile strength ratio (%)	0.92	0.84	0.80	0.94

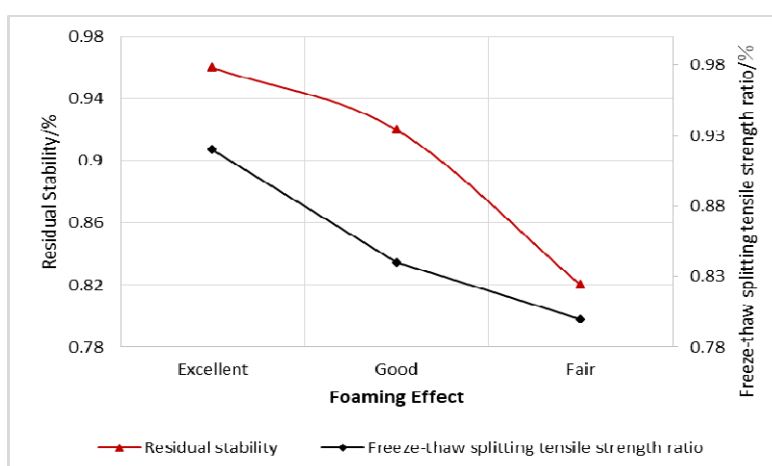


Figure 2 Residual stability and freeze-thaw splitting tensile strength ratio curves of different foaming effects

It is known from Figure 2 and Table 8 that the water stability of the foamed warm-mix asphalt mixture is very sensitive to the foaming effect of the foamed asphalt. The better the foaming effect, the residual stability and freeze-thaw splitting tensile strength ratio The higher the

temperature, the better the water stability of the warm-mix asphalt mixture. Analyzing the reasons, it is known that the foaming effect of asphalt directly reflects the dispersion effect of foamed asphalt. The better the dispersion effect of foamed asphalt, the more uniform the

asphalt film is formed on the aggregate, which further affects the initial strength and spatial structure of the mixture. Thereby affecting the water stability of the mixture. Therefore, the foaming effect of asphalt is an influencing factor of the water stability of the warm-mix asphalt mixture.

At the same time, the residual stability of the hot-mix asphalt mixture is 0.97, and the freeze-thaw splitting tensile strength ratio is 0.94, which is close to the warm-mix asphalt mixture with excellent foaming effect, which indicates the water stability of the warm-mix asphalt mixture. Although the performance is slightly inferior to the hot-mix asphalt mixture, it is far beyond the specification requirements. In engineering applications, using the foamed asphalt with the best foaming effect for the warm-mixing process is beneficial to improve the water stability of the warm-mix asphalt mixture.

4.2 Influence of foaming water consumption

Foamed asphalt is produced by asphalt, water, and gas under high temperature and high pressure. Therefore, there is a small amount of water in the foamed warm asphalt mixture during the molding process. The volume

of the foamed asphalt expands sharply during the molding process, realizing the mixing of asphalt and low-temperature aggregates. Coating, the short mixing time results in the inability of moisture to evaporate completely, and the presence of moisture inevitably reduces the penetration of asphalt to the aggregate, which makes it difficult for the water stability of the asphalt mixture to achieve the effect of the hot-mix asphalt mixture. Therefore, studying and analyzing the influence of foaming water consumption on water stability is an important direction to improve water stability. Since the foaming water consumption also significantly affects the foaming effect of asphalt, in order to control other variables, to study the influence of a single variable foaming water consumption on the water stability of the warm-mix asphalt mixture, the foaming water consumption is divided into 2% , 2.5%, 3%, 3.5%, 4%, fiber content 0%, bitumen temperature 155°C, and adjust the bitumen temperature under the corresponding water consumption, so that the foaming effect under each water consumption is close to the same or similar, and then proceed Warm-mix asphalt mixture preparation, water immersion Marshall and freeze-thaw splitting tests were carried out. The data is shown in the table below.

Table 9 Test data of immersion Marshall and freeze-thaw splitting Water consumption for foaming (%)

Water consumption for foaming (%)	2	2.5	3	3.5	4	hot mix
Stability/KN (Soaking in water for 30min)	11.78	10.47	10.00	10.41	10.62	11.88
Stability/KN (soaked in water for 48h)	11.55	10.16	9.62	9.58	9.45	11.52
Residual stability (%)	0.98	0.97	0.96	0.92	0.89	0.97
Splitting tensile strength before freezing (MPa)	1.40	1.34	1.42	1.31	1.35	1.48
Splitting tensile strength after freezing and thawing (MPa)	1.33	1.25	1.31	1.18	1.15	1.39
Freeze-thaw splitting tensile strength ratio (%)	0.95	0.93	0.92	0.90	0.85	0.94

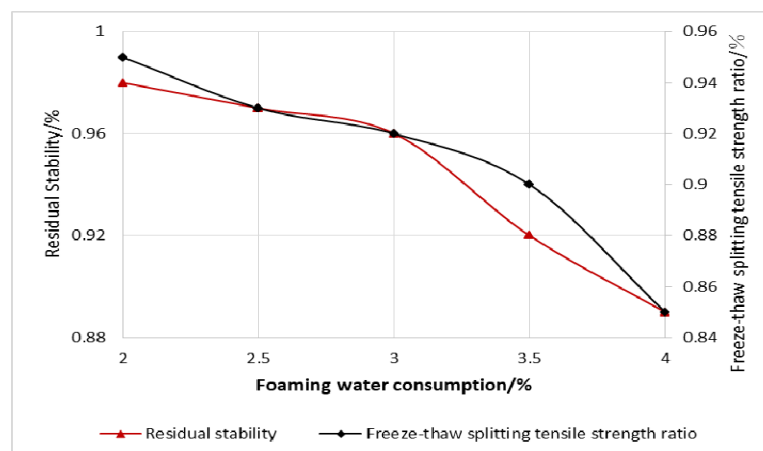


Figure 3 The ratio curve of residual stability and freeze-thaw splitting tensile strength of different foaming water consumption

It can be seen from Table 9 and Figure 3 that under the premise that the foaming effect of the asphalt is basically the same, the residual stability of the warm-mix

asphalt mixture and the freeze-thaw splitting tensile strength ratio increase with the increase of the foaming water consumption. Gradually decrease, when the

foaming water consumption is 2~3.5%, the residual stability and freeze-thaw splitting tensile strength ratio are both higher than 0.9, and when the foaming water consumption is very low (about 2%), warm-mix asphalt The ratio of residual stability and freeze-thaw splitting tensile strength of the mixture is close to that of hot-mix asphalt mixture, and the water stability is stronger; when the foaming water consumption exceeds 3.5%, the residual stability and freeze-thaw splitting tensile strength The intensity ratio is lower than 0.9. This indicates that the presence of water can reduce the adhesion between asphalt and aggregates, which is not conducive to the water stability of warm-mix asphalt mixtures. Therefore, the foamed warm-mix asphalt mixtures should try their best to ensure the foaming effect of foamed asphalt. Reducing the water consumption for foaming (recommended water consumption for foaming is less than 3.5%) is beneficial to improve the water stability of the warm-mix asphalt

mixture.

4.3 Asphalt temperature influence

Asphalt temperature has a strong correlation with the foaming effect of foamed asphalt and the mixing of warm-mix asphalt mixture, which directly restricts the mechanical properties of warm-mix asphalt mixture. In order to explore the correlation between the asphalt temperature and the water stability of the warm-mix asphalt mixture, In this paper, a single variable control method is adopted. The asphalt temperature is set to 135 °C , 145 °C , 155 °C , 165 °C , the foaming water consumption is 3%, and the fiber content is 0%. The warm-mix asphalt mixture is prepared, and the water immersion Marshall and freeze-thaw are carried out.

Split test, as shown in the table below.

Table 10 Water Marshall and Freeze-Thaw Splitting Test Data

Asphalt temperature (°C)	135	145	155	165	Hot mix
Stability/KN (immersed in water for 30min)	11.68	10.60	10.00	10.59	11.88
Stability/KN (soaked in water for 48h)	9.58	9.75	9.62	9.74	11.52
Residual stability (%)	0.82	0.92	0.96	0.92	0.97
Splitting tensile strength before freezing (MPa)	1.21	1.11	1.42	1.19	1.48
Splitting tensile strength after freeze-thaw (MPa)	0.97	0.99	1.31	1.00	1.39
Freeze-thaw splitting tensile strength ratio (%)	0.80	0.89	0.92	0.84	0.94

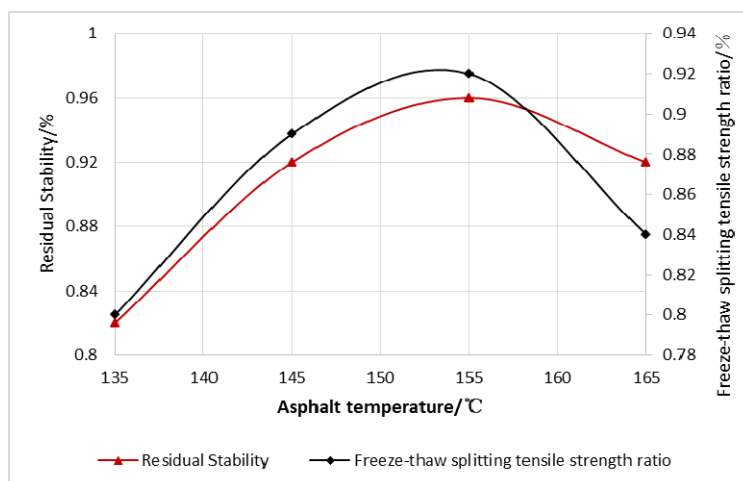


Figure 4 Residual stability and freeze-thaw splitting tensile strength ratio curves of different foaming effects

It can be seen from Table 10 and Figure 4 that the residual stability and freeze-thaw splitting tensile strength ratio of the warm-mix asphalt mixture first increase and then decrease with the increase of the asphalt temperature. When the asphalt temperature is 135 When the temperature is ~155°C, the ratio of residual stability and freeze-thaw splitting tensile strength

gradually increases; when the asphalt temperature is 155 ~ 165 °C , the ratio of residual stability and freeze-thaw splitting tensile strength gradually decreases. At °C, the peak value is reached. It shows that the asphalt temperature does not have a monotonic effect on the water stability performance. The main reason is that the asphalt temperature is an important factor affecting

the asphalt foaming effect. When the foaming water consumption is 3%, the asphalt temperature 155 °C achieves the best water stability performance. The best foaming effect of asphalt is consistent at 155°C, which shows that the influence of asphalt temperature on water stability should be mainly considered from the perspective of asphalt foaming effect. In the case of a certain amount of foaming water, the appropriate asphalt temperature produces the best asphalt foaming effect, which can effectively improve the mixing effect of the asphalt mixture and enhance the internal strength of the mixture, thereby helping to improve the warm-mix asphalt mixture Water-stable performance, so the foamed warm asphalt mixture should adopt the asphalt temperature under the best foaming effect.

4.4 Influence of fiber content

Fiber as an additive for asphalt and asphalt mixtures has been widely used at home and abroad, and has achieved good results [12-16]. As the reinforced fiber of asphalt mixture, polymer fiber has the advantages of high melting point and high elongation at break, which can effectively improve the mechanical properties of asphalt mixture. In this paper, the fiber content is 0%, 0.2%, 0.4%, 0.6%, the asphalt temperature is set to 145°C, the foaming water consumption is 3%, and then the warm mix asphalt mixture is prepared, and the water immersion Marshall and freeze-thaw splitting are carried out. test. The data is shown in the table below.

Table 11 Water immersion Marshall and freeze-thaw split test data

Fiber content (%)	0	0.2	0.4	0.6	Hot mix
Stability/KN (immersed in water for 30min)	10.60	10.12	10.28	10.67	11.88
Stability/KN (soaked in water for 48h)	9.75	9.82	9.97	9.82	11.52
Residual stability (%)	0.92	0.97	0.97	0.92	0.97
Splitting tensile strength before freezing (MPa)	1.11	1.16	1.26	1.20	1.48
Splitting tensile strength after freezing and thawing (MPa)	0.99	1.08	1.16	1.06	1.39
Freeze-thaw splitting tensile strength ratio (%)	0.89	0.93	0.92	0.88	0.94

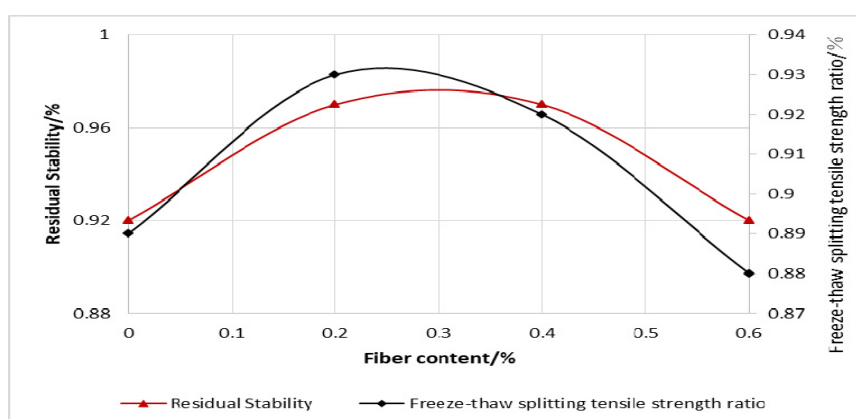


Figure 5 Residual stability and freeze-thaw splitting tensile strength ratio curve of different fiber content

It can be seen from Table 11 and Figure 5 that as the content of polymer fiber increases, the ratio of residual stability and freeze-thaw splitting tensile strength first increases and then decreases, and the fiber content is It reaches the maximum value at 0.2~0.3%. When the fiber content increases and exceeds 0.3%, the ratio of residual stability and freeze-thaw splitting tensile strength decreases with the increase of fiber content. Data analysis shows that the addition of fiber does have a certain degree of influence on the water stability of the warm-mix asphalt mixture, but the influence of fiber content on the water stability is parabolic. When the fiber content is at the optimal value, the temperature The water stability of the asphalt mixture is the strongest. This shows that a proper amount of fiber has a reinforcing effect inside the mixture, which can effectively strengthen the internal structure of the mixture, which is

conductive to its water stability. Too much fiber leads to excessive reinforcement and reduces the stability of the internal structure. Too little content This results in insufficient reinforcement and can not achieve the best water stability. Therefore, in practical engineering applications, you can try to add fibers (with a content of 0.2 to 0.3%) to improve the water stability of the warm-mix asphalt mixture.

4.5 Parameter importance analysis

The random forest algorithm is completed by the statistical language R, with the four influencing factors of A asphalt foaming effect, B asphalt temperature, C foaming water consumption, and D fiber content as input variables. Residual stability and freeze-thaw splitting resistance are used as input variables. The intensity ratio

is used as the output variable to establish a random forest regression model to analyze the importance of the

variable. The following figure lists the variable importance values analyzed by the random forest model.

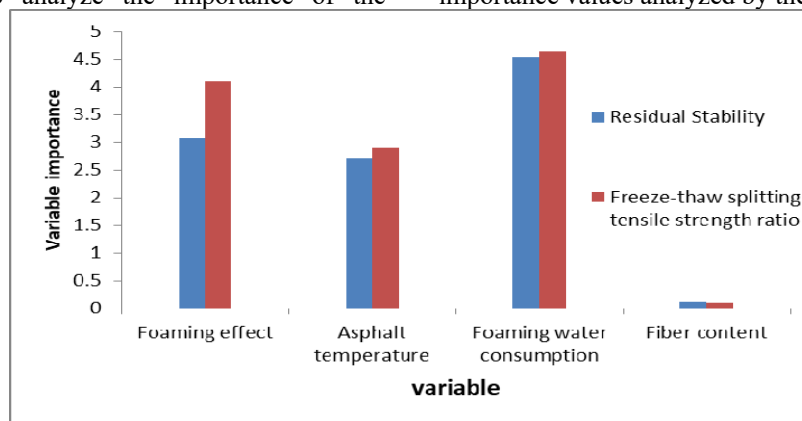


Figure 6 Importance of variables

It can be seen from Figure 6 that according to the relative importance analysis of the random forest algorithm variables, the water stability analysis of the foam warm mix asphalt mixture is related to each influencing factor, but the influence weights are very different. In the analysis of the water stability of the foamed warm-mix asphalt mixture, the foaming water consumption, the foaming effect, and the asphalt temperature are the more important variables, and the fiber content is less important. This shows that in the measures to improve water stability, priority can be given to reducing the foaming water consumption, and then setting the best foaming effect of the foamed asphalt, and then setting the best temperature of the asphalt. Although the fiber content can also improve the water stability, the influence weight is low. When conditions permit, fiber can be added to improve the water stability, but the improvement is not significant. It provides technical guidance with strong operability for improving the water stability of foamed warm-mix asphalt mixture.

5 Conclusion

(1) Asphalt foaming effect, foaming water consumption, asphalt temperature, and fiber content are the direct factors affecting the water stability of warm-mix asphalt mixtures. According to the analysis of the relative importance of the variables of the random forest algorithm, in the water stability analysis of the foam warm mix asphalt mixture, the foaming water consumption, the foaming effect, and the asphalt temperature are the more important variables, and the fiber content is less important. Among the measures to improve water stability, priority can be given to reducing the foaming water consumption, and then setting the best foaming effect of foamed asphalt, and then setting the best asphalt temperature. Although the fiber content can also improve the water stability, it will affect The weight is low.

(2) The foaming effect of foamed asphalt directly determines the uniformity of asphalt film formation on the surface of the aggregate. The excellent foaming effect of asphalt is beneficial to the coating effect of asphalt and aggregate, and will further improve the warm-mix

asphalt mixture. Water stability, therefore, the foamed warm-mix asphalt mixture is as far as possible to select the asphalt with good foaming effect, and use the best foaming effect of the asphalt for the warm-mixing process. The presence of foaming water is not conducive to the water stability of the warm-mix asphalt mixture. The smaller the amount of foaming water, the stronger the water stability. Therefore, the warm-mix asphalt mixture based on foamed asphalt can guarantee the foaming effect of the foamed asphalt. , Minimize the foaming water consumption (recommended foaming water consumption is less than 3.5%), which is beneficial to improve the water stability of the warm-mix asphalt mixture. When the foaming water consumption is constant, the appropriate asphalt temperature is beneficial to improve the water stability of the warm-mix asphalt mixture. Therefore, the warm-mix asphalt mixture based on foamed asphalt should adopt the asphalt temperature with the best foaming effect. A proper amount of fiber can improve the water stability performance. It is recommended to add a proper amount of fiber (0.2-0.3%) during the production of the warm-mix asphalt mixture to improve the water-stability performance of the warm-mix asphalt mixture.

(3) Due to the uniqueness of the foamed warm-mix asphalt mixture, moisture exists in the material. Therefore, water stability is an important index to measure the mechanical properties of the warm-mix asphalt mixture. The results of this study can provide a technical reference for the factors of foaming effect, foaming water consumption, asphalt temperature and fiber content in the design of foamed warm-mix asphalt mixture. After comprehensive analysis, taking the asphalt used in this article as an example, it is recommended to improve the water stability of the warm-mix asphalt mixture with a combination of the best foaming effect, asphalt temperature of 155°C, foaming water consumption of 2%, and fiber content of 0.3%.

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