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Low Temperature Performance Prediction Model of Cold-Filled SMA-13 Asphalt Mixture

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Abstract

Sets of cold-filled SMA-13 asphalt mixture were designed by means of orthogonal design method. The bending and low temperature creep tests of the cold-filled SMA-13 asphalt mixture were carried out. The related models of the fractal dimension and the road performance evaluation index including low temperature bending failure strain ε_B and bending strength R_B are established by using fractal theory. The model can be used to predict the low temperature performance of cold-filled SMA-13 asphalt mixture according to the design gradation, which can reduce the test workload and improve the working efficiency, so as to provide the reference for engineering design.

Keywords

Low Temperature Performance, Prediction Model, Cold-Filled SMA-13 Asphalt Mixture, Fractal Dimension, Evaluation Index

1. Introduction

The heat compensation method is not suitable for construction in a humid, low temperature environment and pollutes the environment. On the basis of the previous research results at home and abroad, the research group, combined with the characteristics of climate, transportation and materials in Northeast China, independently research and develop cold-filled asphalt mixture suitable for the freezing period and with good road performance. Cold-filled asphalt mixture low-temperature performance is an important component of road performance, especially for the northeastern region. If the correlation model between cold-filled asphalt mixture fractal dimension and low temperature performance evaluation index can be established, the low temperature performance of cold-filled asphalt mixture can be predicted through the gradation fractal dimension to reduce the amount of test work. Based on the correlation analysis between the fractal dimension and the evaluation index of low temperature performance, the low temperature performance prediction model is established and the low temperature performance prediction model of cold-filled SMA-13 asphalt mixture is recommended through the comparison of multiple models [1].

2. The Raw Material Performance Test

Liaohe petroleum asphalt grade A No. 90, which is widely used in the northeast of China and the basic performance test results are shown in **Table 1** [2].

The coarse aggregate of cold-filled SMA-13 asphalt mixture use basalt gravel produced by Jilin Dawan Quarry. The basic performance test results are shown in **Table 2** [3].

The fine aggregate should be clean, dry, no weathering, no impurities, and appropriate particle size distribution. Fine aggregate use mechanism sand from limestone produced by Liaoyang Xiaotun Yongli quarries. The basic performance test results are shown in **Table 3**.

Lignin fiber was used, the basic performance test results are shown in **Table 4**.

The variation coefficient of test data in **Tables 1-4** is less than 15%.

24 sets of cold-filled asphalt additive preparation schemes were designed, which were combined with matrix asphalt, thinner and mineral materials to form cold-filled asphalt mixture. The compaction, looseness and low-temperature workability test were tested to select the optimal one. No. 16 cold-filled asphalt liquid was selected [4]. The raw materials used in the test are all in line with the requirements of the road.

3. Cold-Filled Asphalt Mixture Design

The aggregate gradation design scheme and the optimum oil-stone ratio of cold-filled SMA-13 asphalt mixture are shown in **Table 5** [5].

Table 1. No. 90 Class A asphalt test results.

Test items		Test value	Specification requirements
Penetration (25˚C, 100 g, 5 s) 0.1mm		91	80 - 100
Ductility (15˚C) cm		>100	≥100
Softening Point (R & B)˚C		44.5	≥44
Penetration index PI		−1.36	−1.5 - 1.0
60˚C Dynamic viscosity (Pa·s)		163	≥140
Wax content distillation		1.91	≤2.2
Flash point COC (˚C)		245	≥243
Solubility		99.63	≥99.5
Film heating test 163˚C, 5 h	Quality loss (%)	−0.3	±0.8
	Penetration ratio 25˚C (%)	67.4	≥57
	Ductility 10˚C, 5 cm/min (cm)	32	≥8

Table 2. Basalt coarse aggregate technical index.

Material specification (mm)		13.2 - 16	9.5 - 13.2	4.75 - 9.5
Technical index	Standard value	Test value		
Crushing value (%)	≤26	12.4	13.2	13.2
Apparent relative density (T/m^3)	≥2.6	2.94	2.95	2.96
Water absorption rate (%)	≤2.0	0.50	0.86	1.52
Consistency	≤12		8	
Content of needle and sheet granular (%)	≤15	8.2	7.8	6.6
<0.075 Particle content (%)	≤1	0.2	0.2	0.2

Table 3. The technical index of limestone fine aggregate.

Material specification (mm)		2.36 - 4.75	1.18 - 2.36	0 - 1.18
Technical index	Standard value	Test value		
Apparent relative density (T/m^3)	≥2.5	2.687	2.765	2.734
Content of clay (%)	≤3	0.5	1.5	1.5

Table 4. The technical index of lignin fiber.

Test items	Test results	Standard
Fiber length	<6 mm	<6 mm
Ash content	18.6%	18% ± 5%, Non volatile matter
PH value	7.7	7.5 ± 1
Oil absorption rate	5.8	≥5 times quality of fiber
Moisture content	3.5%	<5% (Quality calculation)
Relative density	1.006	

Test results

Trabecular bending test at a temperature of −10˚C were done according to the Standard Test Method of Bitumen and Bituminous Mixtures for Highway Engineering (JTG E20-2011). The experimental results and the corresponding fractal dimensions of the low temperature stability for cold-filled SMA-13 asphalt mixture are summarized in Table 6 [6].

Model building

It can be seen from Table 6 that the range of fractal dimension satisfying the low-temperature bending strain is D = 2.5484 - 2.6122, D_c = 2.0172 - 2.1676, D_f = 2.6695 - 2.8772.

The ternary linear regression model is established through taking ε_B as the dependent variable, taking D, D_c, D_f as the independent variables.

Table 5. The scheme of gradation design of cold-filled SMA-13 asphalt mixture.

No.	Percentage of quality pass (%)										
	16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075	Oil-stone ratio
1	100	95	62.5	27	20.5	19	16	13	12	10	5.03
2	100	95	68.8	30.5	23.3	21.5	18	14.5	13.5	11	5.23
3	100	95	56.3	23.5	17.8	16.5	14	11.5	10.5	9	4.82
4	100	97.5	62.5	27	23.3	21.5	18	11.5	10.5	9	5.04
5	100	97.5	68.8	30.5	17.8	16.5	14	13	12	10	4.92
6	100	97.5	56.3	23.5	20.5	19	16	14.5	13.5	11	5.15
7	100	92.5	62.5	27	17.8	16.5	14	14	13.5	11	5.04
8	100	92.5	68.8	30.5	20.5	19	16	11.5	10.5	9	4.93
9	100	92.5	56.3	23.5	23.3	21.5	18	13	12	10	5.15
10	100	98.1	65.2	25.6	19.8	16.3	13.8	12.4	10.4	8.7	4.93
11	100	97.4	61.1	28.7	22.1	17.8	15.1	13	11.7	10	5.09
12	100	97.7	56.1	26.2	20.9	18.5	15	12.2	11.5	10	5.04
13	100	92.5	67.5	23.5	20	19	16	14	12	10	5.04

Table 6. The fractal dimension of cold-filled SMA-13 asphalt mixture and the low temperature test data.

Gradation number	Average maximum load (N)	Average span deflection (mm)	Bending strain ε_B (με)	Bending strength Mpa	D	D_c	D_f
SMA1	212	2.8	14078	1.79	2.5811	2.0965	2.7723
SMA2	230	3.88	19613	2.00	2.5958	2.1676	2.7640
SMA3	183	1.44	7288	2.02	2.5643	2.0172	2.7826
SMA4	268	1.65	8227	2.90	2.5569	2.1493	2.6695
SMA5	252	2.78	14201	2.10	2.5670	2.0380	2.8325
SMA6	270	1.92	9868	2.34	2.6122	2.0761	2.8170
SMA7	204	3.64	18666	1.68	2.6005	2.0378	2.8772
SMA8	216	3.51	18153	1.74	2.5484	2.1150	2.7224
SMA9	319	2.55	13947	2.17	2.5959	2.1470	2.7193
SMA10	249	2.57	13040	2.18	2.5489	2.0595	2.7769
SMA11	574	1.59	10346	4.99	2.5737	2.1385	2.7959
SMA12	248	2.48	12903	2.01	2.5781	2.1043	2.7833
SMA13	376	2.07	10639	3.07	2.5873	2.0589	2.7722

Note: The second group of bending strain ε_B data in the table is subject to further determination. The variation coefficient of test data in the table is less than 15%.

The correlation model of the bending strain and the fractal dimension is established by the regression analysis, as is shown in Formula (1).

$$\varepsilon_B = -432953 - 20571.98D + 99964.86\, D_{nc} + 104839.34\, D_f \qquad (1)$$

Regression coefficient $R^2 = 0.956$.

The ternary linear correlation models of bending strain and three fractal dimensions are established, the correlations of data in Table 6 are analyzed by using SPSS software to obtain the correlation between the bending strain and fractal dimension, as is shown in Table 7.

It can be seen from Table 7, the correlation sequence of low temperature bending strain ε_B and the fractal dimension D, D_C, D_f from large to small is $D_f > D > D_C$, indicating that the relation between the aggregate fractal dimension and bending strain is relatively large, the correlation between ε_B and D_C is relatively small.

The correlation model of ε_B and D_f is established, as is shown in the formula (2).

$$\varepsilon_B = -115184 + 46204D_f \tag{2}$$

Regression coefficient $R^2 = 0.790$.

The correlation model of ε_B and D, D_f is established, as is shown in the Formula (3).

$$\varepsilon_B = -333868 + 104099D + 28508D_f \tag{3}$$

Regression coefficient $R^2 = 0.998$.

Similarly, the ternary linear regression models of bending strength is established, as is shown in the Formula (4).

$$RB = 59 + 22.55D - 26.96D_c - 21.19D_f \tag{4}$$

Regression coefficient $R^2 = 0.940$.

For the correlation between the bending failure strength and the fractal dimension, the data in Table 6 are analyzed by SPSS software. The relationship between the bending failure strength R_B and the fractal dimension is shown in Table 8.

Table 7. Correlation between low temperature bending failure strain and fractal dimension of cold-filled SMA-13 asphalt mixture.

	ε_B	D	D_c	D_f
ε_B	1.000	0.579	−0.115	0.651
D	0.579	1.000	0.070	0.326
D_c	−0.115	0.070	1.000	−0.818
D_f	0.651	0.326	−0.818	1.000

Table 8. Correlation between low temperature bending strength and fractal dimension of cold-filled SMA-13 asphalt mixture.

	R_B	D	D_c	D_f
R_B	1	0.021	0.193	−0.413
D	0.021	1	−0.061	0.468
D_c	0.193	−0.061	1	−0.791
D_f	−0.413	0.466	−0.791	1

Table 9. The prediction model comparison of bending strain and bending strength for cold-filled SMA-13 asphalt mixture.

Model No.	Model expression	Regression coefficient R^2
1	$\varepsilon_B = -432953 - 20571.98D + 99964.86D_c + 104839.34D_f$	0.956
2	$\varepsilon_B = -115184 + 46204D_f$	0.790
3	$\varepsilon_B = -333868 + 104099D + 28508D_f$	0.998
4	$R_B = 59 + 22.55D - 26.96D_c - 21.19D_f$	0.940

It can be seen from Table 8 that the correlation between the bending strength R_B and the fractal dimension D_C of the coarse aggregate gradation is relatively large. Therefore, a correlation model between the bending strength and the fractal dimension D_C can be established. But the regression coefficient is low.

4. Model Selection

As described above, a correlation model of low-temperature bending strain, bending strength and fractal dimension is established, and the results are summarized in Table 9.

It can be seen from Table 9 that the prediction accuracy of model 1, 3 and 4 is relatively high, and the model 1 and 3 are recommended as the prediction model of low temperature bending strain and the model 4 is recommended as the prediction model of low temperature bending strength through multi-model comparison.

5. Conclusion

The correlation model recommended between the fractal dimension and the evaluation index of low temperature performance can be used to predict the low temperature performance of cold-filled SMA-13 asphalt mixture according to the design gradation, which can reduce the test workload and improve the working efficiency.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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