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Low temperature performance prediction model of GAC-20 modified asphalt mixture

Z H Sun[1], H Y Cheng, G Q Zhu and J Ma

The Transportation Engineering School of Shenyang Jianzhu University, Shenyang, 110168, China

Email: happyforevernicety@126.com

Abstract. 25 sets of GAC-20 modified asphalt mixture were designed by means of orthogonal design method. The bending and low temperature creep tests of the GAC-20 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 GAC-20 modified 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.

1. Introduction

Asphalt mixture low-temperature performance is an important component of road performance, especially for the northeastern region. If the correlation model between asphalt mixture fractal dimension and low temperature performance evaluation index can be established, the low temperature performance of 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 asphalt mixture is recommended through the comparison of multiple models.

2. The raw material performance test

Liaohe petroleum asphalt grade A No.90 [5], which is widely used in the northeast of China and the basic performance test results are shown in Table 1, the basic performance test results of SBS modified asphalt are shown in Table 2 [1].

Table 1. Matrix asphalt technical index.

Detection index	Unit	Test value	Specification requirements
Penetration (25℃, 100g, 5s)	0.1mm	86.3	80-100
Ductility (15℃)	cm	＞100	≥50
Softening Point (R&B)	℃	45.9	≥45

Table 2. SBS Modified asphalt technical index.

Detection index	Unit	Test value	Specification requirements Conclusion
Penetration (25℃, 5s, 100g)	0.1mm	83.6	80~100
Softening Point (R&B)	℃	52.0	≥50
Ductility (5℃, 5cm/min)	cm	＞100	≥40
Kinematic viscosity (135℃)	Pa·s	2.7	≤3
Elastic recovery (25℃)	%	91.2	≥90

The coarse and fine aggregate of GAC-20 modified asphalt mixture use limestone gravel produced by Liaoyang Xiaotun victory quarry. The basic performance test results are shown in Table 3 [3].

Table 3. Technical index of limestone coarse aggregate.

Material specification(mm)		26.5-31.5	19-26.5	16-19	13.2-16	9.5-13.2	4.75-9.5
Technical index	Standard value	Test value					
Crushing value (%)	≤24	15					
Apparent relative density (T/m^3)	≥2.5	2.729	2.726	2.73	2.718	2.729	2.732
Water absorption rate (%)	≤2.0	0.12	1.18	0.26	0.28	0.38	0.62
Adhesion with asphalt (Grade)	≥4	4					
Consistency (%)	≤8	8					
Content of needle and sheet granular (%)	≤12	12					
<0.075Particle content (%)	≤ 1	0.3		0.3	0.3	0.3	0．3

Grade A No.90 road petroleum asphalt, SBS modified additives and limestone were tested in accordance with the requirements of the road usage.

2. Model building

The experimental results and the corresponding fractal dimensions of the low temperature stability requirements in Northeast China are summarized in Table 4.

It can be seen from Table 4 that the range of fractal dimension satisfying the low-temperature bending strain [4] is D=2.3388~2.5835, Dc=2.3048~2.5171, D_f=2.3734~2.5870.

The ternary linear regression model is established through taking ε_B as the dependent variable, taking D, Dc, D_f as the independent variables, the abnormal point in the data is found by using residual error analysis. The regression residual error chart of the low temperature bending strain [2] and fractal dimension are obtained by regression analysis of low-temperature bending strain and fractal dimension by MATLAB program, as is shown in Figure 1.

Table 4. The fractal dimension of GAC-20 modified 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
2	1150	0.53	2973	9.488	2.5352	2.5046	2.5104
7	667	0.57	3010	5.335	2.3405	2.3767	2.4636
9	778	0.53	2818	6.389	2.5367	2.4487	2.5468
11	824	0.63	3254	7.032	2.5026	2.3988	2.4749
16	701	0.55	2883	5.825	2.3388	2.3048	2.4281
21	883	0.7	3765	7.281	2.4860	2.5171	2.3734
22	1116	0.64	3371	9.199	2.4282	2.4895	2.5870
24	797	0.54	2812	6.571	2.5835	2.5044	2.4632

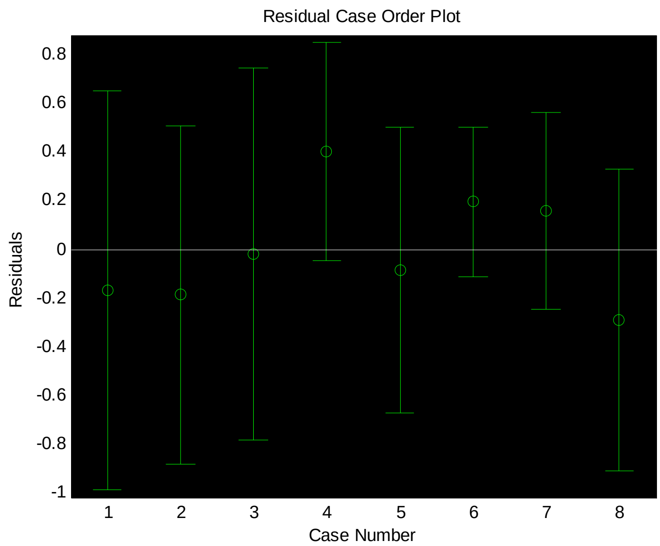

Figure 1. The residual diagram of low temperature bending strain and fractal dimension for GAC-20 modified asphalt mixture.

It can be seen from Figure 1 that there is no abnormal data, the correlation model of the bending strain and the fractal dimension [6-8] is established by the regression analysis, as is shown in formula (1).

$$\varepsilon_B=3884.8-2574.8D+4145.9D_c-1832.3D_f \quad (1)$$

Regression coefficient R^2=0.5075.

The regression coefficient is low in formula (1), it can be seen from Figure 1, the data of gradation GAC-20-11 can be considered to eliminate as it is unbalanced and larger deviation, the regression model of bending strain and fractal dimension is obtained by applying software MATLAB, as is shown in formula (2).

$$\varepsilon_B=-524.3-2779.6D+2999.9Dc+1210.9D_f \quad (2)$$

Regression coefficient R^2=0.9446.

Similarly, the ternarylinear regression models of bending strength is established, as is shown in the formula (3).

$$R_B=-39.9567-4.0288D+14.8868Dc+8.3331Df \quad (3)$$

Regression coefficient R^2=0.5784.

The ternary linear correlation models of bending strength and bending strain with three fractal dimensions are respectively established, the correlations of data in Table 4 are analyzed by using SPSS software to obtain the correlation between the bending strain, bending strength and fractal dimension, as is shown in Table 5.

Table 5. Correlation between low temperature performance evaluation index and fractal dimension of GAC-20 modified asphalt mixture.

	ε_B	R_B	D	D_c	D_f
ε_B	1.000	0.334	-0.072	0.360	-0.307
R_B	0.334	1.000	0.373	0.649	0.476
D	-0.072	0.373	1.000	0.735	0.166
D_c	0.360	0.649	0.735	1.000	0.190
D_f	-0.307	0.476	0.166	0.190	1.000

It can be seen from Table 5, the correlation sequence of low temperature bending strain ε_B and the fractal dimension D, D_C, D_f from large to small is $D_c > D_f > D$, indicating that the relation between the coarse aggregate fractal dimension and bending strain is relatively large, the correlation between ε_B and D is relatively small.

The correlation between R_B and D_c is larger, the correlation between R_B and D is smaller, the correlation of bending strength R_B and fractal dimension D, Dc, D_f is larger than the bending strain ε_B. The correlation model of ε_B, R_B and the larger correlated fractal dimension is established.

The correlation model of ε_B and D_c is established, as is shown in the formula (4).

$$\varepsilon_B=8484.9D_c^2-39460D_c+48828 \quad (4)$$

Regression coefficient R^2=0.1431.

The correlation model of R_B and D_c is established, as is shown in the formula (5).

$$R_B=33.656D_c^2-150.03D_c+172.62 \quad (5)$$

Regression coefficient R^2=0.4309.

Earlier, the ternary linear correlation model of low temperature index and fractal dimension, and the model of low temperature index and larger correlation fractal dimension are established; then how is the correlation between low temperature performance indexes and two fractal dimension, the correlation model of bending strain, bending strength and two larger correlated fractal dimension are established by using software MATLAB.

The correlation model of ε_B and fractal dimension D, D_c is established, as is shown in formula (6).

$$\varepsilon_B=1086.9-3195.7D+4000.6D_c \quad (6)$$

Regression coefficient R^2=0.886.

The correlation model of bending strain ε_B and fractal dimension D_c, D_f is established, as is shown in the formula (7).

$$\varepsilon_B=-2215.38-725.198D_c+2784.562D_f \quad (7)$$

Regression coefficient R^2=0.432.

The correlation model of bending strength R_B and fractal dimension D_c, D_f is established, as is shown in the formula (8).

$$R_B=-40.908+11.359D_c+8.181D_f \quad (8)$$

Regression coefficient R^2=0.550.

3. 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 6. It can be seen from Table 6 that the prediction accuracy of model 1 and 5, namely, ternary linear predictive model is relatively high, and the model 1 and 5 are recommended as the prediction model of low temperature bending strain and bending strength through multi-model comparison.

Table 6. The prediction model comparison of bending strain and bending strength for GAC-20 modified asphalt mixture.

Model No.	Model expression	Regression coefficient	Advantages and disadvantages
1	$\varepsilon_B = -524.3 - 2779.6D + 2999.9Dc + 1210.9D_f$	0.9446	Higher regression coefficient, Factor analysis is more comprehensive
2	$\varepsilon_B = 8484.9D_c^2 - 39460D_c + 48828$	0.1431	Low regression coefficient, Factor analysis is single
3	$\varepsilon_B = 1086.9 - 3195.7D + 4000.6D_c$	0.8860	Higher regression coefficient
4	$\varepsilon_B = -2215.38 - 725.198D_c + 2784.562D_f$	0.4320	Low regression coefficient
5	$R_B = -39.9567 - 4.0288D + 14.8868Dc + 8.3331D_f$	0.5784	Low regression coefficient Factor analysis is more comprehensive
6	$R_B = 33.656D_c^2 - 150.03D_c + 172.62$	0.4309	Low regression coefficient Factor analysis is single
7	$R_B = -40.908 + 11.359D_c + 8.181D_f$	0.5500	Low regression coefficient

4. 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 GAC-20 modified asphalt mixture according to the design gradation, which can reduce the test workload and improve the working efficiency

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References

[1] Sun Z H, Zhu G Q, Ma J and Bin Q 2014 Comparison Study on Road Performance of Modified Asphalt Mixture for Intermediate Course *Advanced Materials Research* **941-944** 287-290
[2] Occupation Standard of the People's Republic of China JTG E20-2011 2011 Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering
[3] Occupation Standard of the People's Republic of China JTG E42-2005 2005 Test Methods of Aggregate for Highway Engineering
[4] Sun Z H, Yu Q B, Wang T B, Yu B Y, Zhu G Q and Ma J 2014 The Effect of Asphalt and Aggregate Gradation on the Low-temperature Performance of Asphalt Mixtures for Intermediate and Underlying Course *Applied Mechanics and Materials* **505-506** 251-254
[5] Highway Science Research Institute, Ministry of Communications JTG F40-2004 2004 Technical Specifications for Construction of Highway Asphalt Pavements
[6] Sun Z H, Yang G F, Yu B Y and Wang T B 2010 Study on the Gradation Inspection Methold Based on Fractal Theory *Journal of Shenyang Jianzhu University (Natural Science)* **26**(5)

IOP Conf. Series: Materials Science and Engineering **164** (2017) 012022 doi:10.1088/1757-899X/164/1/012022

875-880
[7] R K Chakraborti, K H Gardner, J F Atkinson and J E V Benschoten 2003 Changes in Fractal Dimension during Aggregation *Water Research* **37**(4) 873-883
[8] Villani M M 2014 Application of Fractal Analysis for Measuring the Effects of Rubber Polishing on the Friction of Asphalt Concrete Mixtures *Wear* **320**(1) 179-188