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

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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].

| Detection index                  | Unit | Test value | Specification requirements |
|----------------------------------|------|------------|----------------------------|
| Penetration (25°C, 100g, 5s)     | 0.1mm| 86.3       | 80-100                      |
| Ductility (15°C)                 | cm   | >100       | ≥50                         |
| Softening Point (R&B)           | °C   | 45.9       | ≥45                         |
| Detection index | Unit             | Test value | Specification requirements | Conclusion |
|-----------------|------------------|------------|-----------------------------|------------|
| Penetration     | 0.1mm            | 83.6       | 80~100                      |            |
| Softening Point | °C               | 52.0       | ≥50                         |            |
| Ductility       | cm               | ≥100       | ≥40                         |            |
| Kinematic viscosity | Pa·s | 2.7        | ≤3                          |            |
| Elastic recovery| %                | 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/m³) | ≥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 |       |       |         |          |          |
| Consistency (%)             | ≤8         | 8       |       |         |          |          |
| Content of needle and sheet granular (%) | ≤12 |       |       |         |          |          |
| <0.075Particle content (%) | ≤1         | 0.3     | 0.3   | 0.3     | 0.3     | 0.3     |

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].

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, Df=2.3734~2.5870.

The ternary linear regression model is established through taking $\varepsilon_B$ as the dependent variable, taking D, Dc, Df 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 $\varepsilon_B$ ($\mu\varepsilon$) | 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).

$$\varepsilon_B = 3884.8 - 2574.8D + 4145.9D_c - 1832.3D_f$$

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).

$$\varepsilon_B = -524.3 - 2779.6D + 2999.9D_c + 1210.9D_f$$

Regression coefficient $R^2 = 0.9446$. 


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

$$R_B = -39.9567 - 4.0288D + 14.8868D_c + 8.3331D_f$$  \( (3) \)

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.

|       | $e_B$  | $R_B$  | $D$   | $D_c$  | $D_f$  |
|-------|--------|--------|-------|--------|--------|
| $e_B$ | 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 $e_B$ 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 $e_B$ 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 $D$, $D_c$, $D_f$ is larger than the bending strain $e_B$. The correlation model of $e_B$, $R_B$ and the larger correlated fractal dimension is established.

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

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

Regression coefficient $R^2 = 0.1431$.

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

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

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 $e_B$ and fractal dimension $D$, $D_c$ is established, as is shown in formula (6).

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

Regression coefficient $R^2 = 0.886$.

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

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

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).

$$R_B = -40.908 + 11.359D_c + 8.181D_f$$  \( (8) \)
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         | $\varepsilon_B=8484.9Dc^2-39460Dc+48828$ | 0.1431 | Low regression coefficient, Factor analysis is single |
| 3         | $\varepsilon_B=1086.9-3195.7Dc+4000.6D_c$ | 0.8860 | Higher regression coefficient |
| 4         | $\varepsilon_B=-2215.38-725.198Dc+2784.562D_f$ | 0.4320 | Low regression coefficient |
| 5         | $R_B=-39.9567-4.0288Dc+14.8868Dc+8.3331D_f$ | 0.5784 | Factor analysis is more comprehensive |
| 6         | $R_B=33.656Dc^2-150.03Dc+172.62$ | 0.4309 | Low regression coefficient, Factor analysis is single |
| 7         | $R_B=-40.908+11.359Dc+8.181D_f$ | 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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