Road Performance Prediction Model of AC-25 Asphalt Mixture

Zhaohui Sun*, Zhiqi Song, Guangqiang Zhu and Mengmeng Li

The Transportation Engineering School of Shenyang Jianzhu University, China

*Email: happyforevernicety@126.com

Abstract. 25 groups of AC-25 asphalt mixture are designed by referencing the orthogonal design method, the high temperature rutting and freeze-thaw cycle test are carried out, the related model of the fractal dimension and the road performance evaluation index including dynamic stability and freeze-thaw cycle dynamic stability ratio is established by using fractal theory. The high temperature stability and water stability performance of AC-25 asphalt mixture can be predicted according to the gradation designed. This can reduce the test workload, improve work efficiency, and offer the reference for engineering design.

1. Introduction

The design of asphalt mixture has an important influence on asphalt pavement. There are a certain correlation between the distribution of asphalt mixture gradation and fractal theory. The correlation analysis can be carried out between the fractal dimension and the road performance. In this paper, we analyse the correlation between the fractal dimension and the performance evaluation index of asphalt mixture, and establish the correlation model between the fractal dimension and the pavement performance evaluation index. The road performance prediction model can be obtained.

2. The raw material performance test

Liaohepetroleum 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.

| Detection index          | Unit | Test value | Specification requirements | Conclusion |
|--------------------------|------|------------|----------------------------|------------|
| 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                        |            |

The coarse and fine aggregate of AC-25 mixture use limestone gravel produced by Liaoyang Xiaotun victory quarry. The basic performance test results are shown in table 2. [3]
Table 2. Technical index of limestone coarse aggregate

| Technical index                        | Material specification (mm) | 26.5-31.5 | 19-26.5 | 16-19 | 13.2-16 | 9.5-13.2 | 4.75-9.5 |
|----------------------------------------|----------------------------|-----------|---------|-------|---------|----------|----------|
| Crushing value (%)                     | Standard value             | ≤24       |         |       |         |          |          |
|                                       | Test value                 | 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                         | 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      | 0.3      |

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

3. Road performance test

Using the orthogonal test method for reference to design 25 groups of AC-25 modified asphalt mixture, the rutting test and water stability test were carried out under the wheel pressure is 0.84 MPa. Test results are shown in table 3.

3.1 High temperature performance test

The technical requirements for the dynamic stability of asphalt mixture rutting test are different according to different climate zones and the type of asphalt and mixture in the current specification. Climate zoning in the Northeast of China is belonging to the 2-1 (hot in summer and severe cold in winter) area and 2-2 (hot in summer and cold in winter) area, due to the wheel pressure 0.84 MPa was adopted in rutting test, dynamic stability should be reduced from relevant literature to meet greater than or equal to 667 times / mm. Therefore, the high temperature stability of AC-25 mixture with the grading number of 4, 10, 11, 12, 15, 17, 18, 20 and 25 can meet the requirements.

3.2 Water stability test

The traditional Marshall hammer compaction test method is used to make the test piece, it cannot simulate the driving compaction; the larger size of the aggregate according with the quality requirements of the road is easy to be broken under the standard compaction conditions, the test data is discrete, and there is no direct connection with the performance of the road. Aiming at the shortage of current test method and the characteristics of the Northeast region, in this paper, a new method the wheel rutting test under the condition of freezing and thawing cycle is put forward to simulate the stress state of asphalt mixture in the actual pavement. It can better simulate the water stability of asphalt mixture in the Northeast of China.[5]

The dynamic stability ratio of asphalt mixture was proposed to evaluate the water stability of it. The dynamic stability ratio is defined as the ratio of the dynamic stability of the specimen after freezing thawing cycles and the dynamic stability of non-freezing and thawing cycles as is shown in the formula (1). There is currently no corresponding technical standards in specification, combining with the climatic zoning of the Northeast area belonged to, 0.80 is recommended as the standard value of dynamic stability ratio which is evaluation index of freeze-thaw cycle rutting test, which requires the dynamic stability ratio DSR is more than or equal to 80%.

\[
DSR = \frac{DS_{fs}}{DS_{0}}
\]  

(1)
Where:
DSR—dynamic stability ratio;
\( DS_{dr} \)—the dynamic stability of the specimen after freezing and thawing cycles (times/mm);
\( DS_0 \)—the dynamic stability of non-freezing and thawing cycles (times/mm).

The test results of AC-25 asphalt mixture satisfying high temperature and water stability performance requirements at the same time are shown in table 3. The AC-25 mixture which aggregate gradation number is 4, 12, 15, 17,18and20 meet the water stability requirements.

| Gradation | The optimum asphalt aggregate ratio/% | Dynamic stability \( DS_0 \) (times/mm) | \( DS_{dr} \) (times/mm) | DSR  |
|-----------|--------------------------------------|------------------------------------------|--------------------------|------|
| AC-25-4   | 4.00                                 | 678                                      | 586                      | 0.86 |
| AC-25-12  | 3.96                                 | 800                                      | 707                      | 0.88 |
| AC-25-15  | 3.93                                 | 722                                      | 599                      | 0.83 |
| AC-25-17  | 3.96                                 | 1104                                     | 911                      | 0.83 |
| AC-25-18  | 3.99                                 | 719                                      | 591                      | 0.82 |
| AC-25-20  | 3.93                                 | 671                                      | 589                      | 0.88 |

4. Road performance model
The rutting test results of meeting the above high temperature stability requirements in the Northeast of China and the corresponding fractal dimension are summarized in Table 4.

| Grading  | Grading fractal dimension D | Coarse aggregate fractal dimension \( D_c \) | Fine aggregate fractal dimension \( D_f \) |
|----------|-----------------------------|---------------------------------------------|------------------------------------------|
| AC-25-4  | 2.4495                      | 2.3906                                      | 2.4877                                   |
| AC-25-12 | 2.4917                      | 2.5823                                      | 2.4256                                   |
| AC-25-15 | 2.6117                      | 2.3046                                      | 2.5689                                   |
| AC-25-17 | 2.5973                      | 2.5915                                      | 2.5581                                   |
| AC-25-18 | 2.5607                      | 2.5098                                      | 2.5809                                   |
| AC-25-20 | 2.4641                      | 2.3147                                      | 2.3781                                   |

As can be seen from table 4, the fractal dimension range of meeting the requirement of dynamic stability and water stability performance is \( D = [2.4495, 2.6117] \), \( D_c = [2.3046, 2.5915] \), \( D_f = [2.3781, 2.5809] \).

4.1 High temperature performance model
There is a correlation between the high temperature performance of asphalt mixture and fractal dimension. First of all, ternary linear regression is analyzed between the fractal dimension and dynamic stability, the ternary element linear regression model of dynamic stability and fractal dimension is established. The residual chart of dynamic stability and fractal dimension is drawn by the software MATLAB to check out the abnormal data. The fourth data can be regarded as abnormal points in the data analysis, the fourth data is excluding, the ternary linear regression analysis is done to obtain the correlation model of dynamic stability as can be seen in formula (2).

\[
DS = -823.592 + 651.065D + 361.198D_c - 390.008D_f
\]  

(2)

The regression coefficient \( R^2 = 0.843 \)
This can be shown that the three element linear regression model can be established between dynamic stability and fractal dimension, and the regression coefficient is higher, so there are the correlation between dynamic stability and the fractal dimension, the correlation analysis is done by data in Table 3 and table 4, the correlation analysis results are shown in Table 5.

It can be seen from table 5, the correlation between the fractal dimension and DS ordered from the big to small is Dc>D>Df. The influence of coarse aggregate fractal dimension on dynamic stability is relatively large, but the correlation coefficient between DS and the fine aggregate fractal dimension Df is relatively small. So the correlation model between the fractal dimension of the coarse aggregate and the dynamic stability can be established. The related model of dynamic stability DS and Dc is shown in formula (3).

\[
DS = 319.433D_c - 55.156
\]  

The regression coefficient $R^2 = 0.577$

**Table 5.** The correlation of dynamic stability and fractal dimension

|     | D  | Dc | Df | DS  |
|-----|----|----|----|-----|
| D  | 1.000 | -0.106 | 0.789 | 0.251 |
| Dc | -0.106 | 1.000 | 0.011 | 0.760 |
| Df | 0.789 | 0.011 | 1.000 | 0.026 |
| DS | 0.251 | 0.760 | 0.026 | 1.000 |

The correlation model of dynamic stability and two fractal dimensions D, Dc is established. As is shown in formula (4):

\[
DS = -721.0 + 250.3D + 334.3D_c
\]  

The regression coefficient $R^2 = 0.688.$

The correlation model of dynamic stability and two fractal dimensions Dc, Df is established. As is shown in formula (5):

\[
DS = -81.3 + 319.4D_c + 10.6D_f
\]  

The regression coefficient $R^2 = 0.577.$

5. Model selection

**Table 6.** Prediction model of dynamic stability

| No. | Model expression | Regression coefficient $R^2$ | Characteristics |
|-----|------------------|------------------------------|-----------------|
| 1   | \(DS = -823.6 + 651.1D + 361.2D_c - 390.0D_f\) | 0.853 | The regression coefficient is higher and the analysis of the factors is more comprehensive |
| 2   | \(DS = 319.433D_c - 55.156\) | 0.577 | The regression coefficient is low and the analysis of the influence factors is relatively simple |
| 3   | \(DS = -721.0 + 250.3D + 334.3D_c\) | 0.688 | The regression coefficient is lower |
| 4   | \(DS = -81.3 + 319.4D_c + 10.6D_f\) | 0.577 | The regression coefficient is lower |

The correlation model of dynamic stability and fractal dimension established is included in Table 6. It can be seen from table 6 that the prediction accuracy of three element linear model is higher than the others. Thus, the model 1 is recommended to predict the dynamic stability by model selection.

In the same way, the correlation model of dynamic stability ratio and fractal dimension is established according to the above method. The summary is listed in Table 7. It can be seen that from
Table 7. The regression coefficients of model 1 and 4 are relatively higher, and the model 1 and 4 are recommended to be used as the water stability prediction model.

Table 7. Prediction model of dynamic stability ratio

| No. | Model expression       | Regression coefficient R² | Characteristics                        |
|-----|------------------------|----------------------------|----------------------------------------|
| 1   | DSR=1.650-0.048D+0.011Dc-0.283Df | 0.959                     | The regression coefficient is relatively higher |
| 2   | DSR=1.629-0.312Df      | 0.951                     | The regression coefficient is relatively higher |
| 3   | DSR=1.661-0.321D       | 0.697                     | The regression coefficient is lower     |
| 4   | DSR=1.668-0.046D-0.280Df | 0.956                     | The regression coefficient is relatively higher |

6. Conclusions
By the results of the above experiments, the high temperature performance prediction model of AC-25 mixture is DS=-823.592+651.065D+361.198Dc-390.008 Df;

The water stability prediction model is

DSR=1.650-0.048D+0.011Dc-0.283Df

or DSR=1.668-0.046D-0.280Df

These models are used to predict the performance of AC-25 mixture; it can reduce the amount of testing, improve the working efficiency, and can be used for engineering design.

7. Acknowledgments
This work was financially supported by the Natural Science Foundation of China (51178278).

8. References
[1] Occupation Standard of the People’s Republic of China., JTG E20-2011 “Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering” [S]
[2] Highway Science Research Institute, Ministry of Communications JTG F40-2004“Technical Specifications for Construction of Highway Asphalt Pavements” [S]
[3] Occupation Standard of the People’s Republic of China, JTG E42-2005 “Test Methods of Aggregate for Highway Engineering” [S]
[4] Al-Swailmi S., Evaluation of Water Damage of Asphalt Concrete Mixtures Using the Environmental Conditioning System (ECS). Proceedings, 2012.
[5] Zhao-Hui SUN, Tie-Bin WANG, Ze-Feng WU and Zhi-Song WANG, Research on the Evaluation Method of Water Stability for Large Size aggregate Particle Asphalt Mixture Applied Mechanics and Materials Vol. 692 (2014) pp 497-500 Submitted: 10. 09. 2014