# Predictive Modeling of High Temperature Performance of SMA-13 Cold Patch Asphalt Mixture Based on Fractal Theory

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**Abstract.** In order to study the relationship between the high temperature performance of cold-patched asphalt mixtures and gradation fractal, 13 groups of SMA-13 asphalt mixtures were designed, and high temperature rutting test was carried out to study the high temperature performance of cold-patched asphalt mixtures, and the fractal theory was applied to get the overall fractal dimension D , coarse aggregate fractal dimension $D_c$ , fine aggregate fractal dimension $D_f$, and the predictive model of high temperature performance for cold-patched asphalt mixtures was set up according to the correlation analysis of the high temperature performance and fractal dimension. The high-temperature performance prediction model of cold-patched asphalt mixtures was established based on the correlation analysis between high-temperature performance and fractal dimension. This can reduce the test workload, improve work efficiency, and provide reference for engineering design.

## 1. INTRODUCTORY

In order to optimize the SMA-13 graded asphalt mixture, to extend the service life of the road, 13 groups of SMA-13 high temperature performance experiments, and based on the fractal theory, the high temperature performance parameters obtained from the test and the overall graded fractal dimension, coarse aggregate fractal dimension, fine aggregate fractal dimension linear fitting[1], from the perspective of high strength correlation to reveal the focus of the influence of aggregate specifications on the performance of the mixture, to establish a correlation model of fractal dimension and the evaluation indexes of high temperature performance of pavement . The correlation model between fractal dimension and pavement high temperature performance evaluation indexes was established at[2].

## 2. EXPERIMENTAL

### 2.1. Raw materials

Basalt crushed stone was used for coarse aggregate and limestone crushed stone for fine aggregate. The specifications of coarse aggregate are 4.75 ~ 9.5mm, 9.5 ~ 13.2mm, and 13.2 ~ 16mm. the main technical indexes are shown in table 1. All the indicators meet the requirements of the specification[3].

The specification of fine aggregate is 0~1.18 mm, 1.18~2.36 mm, and 2.3~4.75 mm,the main technical indexes are shown in the table 2. All indicators are in accordance with the specification.

**Table 1.** The technical index of coarse aggregate.

| Technical index name | 13.2~16 | 9.5~13.2 | 4.75~9.5 | Technical standards | Conclusion | Test method |
|---|---|---|---|---|---|---|
| Apparent specific gravity | 2.734 | 2.785 | 2.845 | ≥2.6 | Qualification | T0304 |
| Relative density of bulk volume | 2.751 | 2.770 | 2.814 | — | — | T0304 |
| Crush value (%) | 13.2 | 13.2 | 12.4 | ≤26 | Qualification | T0316 |
| Water washi-ng method < 0.075mm (%) | 0.2 | 0.2 | 0.2 | ≤1 | Qualification | T0310 |
| Needle flake content (%) | 6.6 | 7.8 | 7.8 | ≤15 | Qualification | T0312 |

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| Technical index name | 13.2~16 | 9.5~13.2 | 4.75~9.5 | Technical standards | Conclusion | Test method |
|---|---|---|---|---|---|---|
| Water absorption (%) | 1.52 | 0.89 | 0.49 | ≤2.0 | Qualification | T0304 |
| Soundness (%) | 8 | 8 | 8 | ≤12 | Qualification | T0314 |
| Soft stone content (%) | 1.2 | 1.2 | 1.2 | ≤3 | Qualification | T0320 |

**Table 2.** The technical index of fine aggregate.

| Technical index name | Particle size (mm) | Unit | Specification requirements value | Experimental value |
|---|---|---|---|---|
| Apparent specific gravity | 2.36~4.75 | — | ≥2.5 | 2.667 |
| | 1.18~2.36 | | | 2.763 |
| | 0~1.18 | | | 2.758 |
| Soil content | | % | ≤3 | 1.37 |

The filler in this paper is limestone-based mineral powder and 42.5 grade ordinary silicate cement. The technical specifications of the fillers are shown in Table 3[4]

**Table 3.** The technical parameter of filler.

| Technical index name | Unit | Specification requirements value | Experimental value | |
|---|---|---|---|---|
| | | | Mineral fines | Cement |
| Apparent density | g/cm3 | ≥2.5 | 2.727 | 3.034 |
| Appearance | | Be without block | Be without block | |
| Hydrophilic coefficient | | <1 | - | - |
| Water content | % | <1 | 0.045 | 0.066 |

Based on the research of pavement performance in Northeast China, and taking into account the climate characteristics of Northeast China in recent years and the classification of climate zones[5], 90 road petroleum asphalt was selected as the base asphalt[6], and the basic indexes of the test are shown in Table 4.

**Table 4.** The test findings of the conventional index of 90 base asphalt.

| Test Indicator Name | Unit | Specification requirement | Test result |
|---|---|---|---|
| Penetration degree 25°C, 100g、5s | 0.1mm | 80-100 | 87.4 |
| Extensibility15°C | cm | ≥50 | ＞100 |
| Softening point global method | °C | ≥45 | 45.5 |

From the test results, it can be seen that the selected 90# matrix asphalt meets the requirements and can be used as the main material for the later test.

Cold mix asphalt mixtures require a certain degree of ease of construction, so it is necessary to choose the appropriate diluent. The diluent should have good volatility and good compatibility with the asphalt. In this paper, diesel fuel is used as the diluent of cold patch asphalt, which has a good volatilization rate, a flash point greater than 55°C, and is relatively safe to use. At the same time, the use of self-developed cold patch additives, add a certain proportion of cold patch asphalt, its main mechanism is, without changing the viscosity of cold patch asphalt, to improve the adhesion between cold patch asphalt and the mineral material, to improve the bonding capacity with the original more "dust" or wet pavement between the bonding ability to contribute to the formation of the initial strength of the mixture[7].

## 2.2. Road performance experiments

Highway Engineering Asphalt and Asphalt Mixture Test Specification (JTGE20-2011) emphasizes that the rutting test of asphalt mixture is suitable for high temperature rutting resistance and high temperature stability test, so this paper adopts the rutting test for the test8, and adopts the milling rutting specimen[8]. Considering the climate and temperature of the Northeast region, as well as the unique mechanism of cold-patched asphalt mixtures, the temperature was set to 45°C. In recent years, the increasing traffic volume and the required performance of road surfaces have led to an increase in tire ground pressure from 0.7 MPa to 0.84MPa during rutting tests. The rutted specimens were rolled into shape and allowed to incubate at room temperature 48 h, and then incubated in the rutting room thermometer for not less than 5 h, and rutting test was carried out by automatic rutting tester. The results of the test are shown in Table 5[9].

**Table 5.** The result of the Wheel tracking test.

| Gradation type | Oil rock ratio | Dynamic stability |
|---|---|---|
| 1- SMA -13 | 5.0 | 2138 |
| 2- SMA -13 | 5.2 | 3140 |
| 3- SMA -13 | 4.8 | 2626 |
| 4- SMA -13 | 5.0 | 2878 |
| 5- SMA -13 | 4.9 | 3408 |
| 6- SMA -13 | 5.1 | 4392 |

| Gradation type | Oil rock ratio | Dynamic stability |
|---|---|---|
| 7- SMA -13 | 5.0 | 2518 |
| 8- SMA -13 | 4.9 | 3544 |
| 9- SMA -13 | 5.1 | 4219 |
| 10- SMA -13 | 4.9 | 2196 |
| 11- SMA -13 | 5.0 | 3093 |
| 12- SMA -13 | 5.0 | 2630 |
| 13- SMA -13 | 5.2 | 3075 |

## 3. High temperature prediction modeling

Currently there is no direct conversion method between temperature and dynamic stability, considering the reason of heavy load, set the temperature condition (for 45 ℃, not 60 ℃)[10], appropriate selection of cold patch asphalt mixture rutting index qualification standard for 3000 times/mm. The results after the rutting test data were collated with the fractal dimensions of each set of grades are shown in Table 6.

**Table 6.** Statistics findings of SMA-13 rutting test and dimension.

| Gradu-ation type | Fractal dimension (D) | Fractal dimension of coarse aggregate ($D_c$) | Fractal dimension of fine aggregate ($D_f$) | Average dynamic stability (DS) |
|---|---|---|---|---|
| 5-SMA-13 | 2.5657 | 1.9500 | 2.8359 | 3408 |
| 6-SMA-13 | 2.6106 | 1.7209 | 2.8235 | 4392 |
| 8-SMA-13 | 2.5454 | 1.9659 | 2.7390 | 3544 |
| 9-SMA-13 | 2.5944 | 1.7368 | 2.7361 | 4219 |
| 11-SMA-13 | 2.5718 | 1.9052 | 2.7784 | 3093 |

As can be seen from Table 6, the range of fractal dimensions that satisfy the requirement of dynamic stability is $D = [2.5454,2.6106]$ , and the fractal dimensions that satisfy the requirement of dynamic stability are as follows: $Dc = [1.7209,1.9659], D_f = [2.7361,2.8359]$ .

The grading difference directly affects the grading fractal dimension, fine aggregate fractal dimension and coarse aggregate fractal dimension, nevertheless, there is a certain correlation between these three fractal dimensions, and the correlation between them is obtained by using the SPSS software at, and the approximation matrix is shown in Table 7.

**Table 7.** The approximate matrix of SMA-13 high-temperature indicator.

| SMA-13 | Gradation fractal dimension (D) | Fractal dimension of coarse aggregate ($D_c$) | Fractal dimensi on of fine aggregat e ($D_f$) | Average dynamic stability (DS) |
|---|---|---|---|---|
| Gradation fractal dimension (D) | 1 | -0.95 | 0.289 | 0.884 |
| Fractal dimension of coarse aggregate ($D_c$) | -0.95 | 1 | -0.001 | -0.921 |
| Fractal dimension of fine aggregate ($D_f$) | 0.289 | 0.001 | 1 | 0.169 |
| Average dynamic stability (DS) | 0.884 | -0.921 | 0.2 | 1 |

From Table 7, it can be seen that DS and D, $D_c$, $D_f$ have some correlation, DS and D have a correlation of 0.884, which shows a positive correlation; DS and $D_c$ have a higher correlation of 0.921 and a negative correlation; DS and $D_f$ have a weaker correlation of 0.2, which is a positive correlation. It shows that the correlation between DS and $D_c$. D is much stronger than that of fine aggregates, and with the increase of $D_c$ , the content of coarse material increases, the skeleton effect is relatively weakened, and the thermal stability of cold-patched asphalt mixtures deteriorates, and DS decreases.

A fractal prediction model for the dynamic stability DS is developed below. Try to use computer simulation software to establish three-dimensional linear regression equation, one-dimensional quadratic linear regression equation and two-dimensional linear regression equation related to three fractal dimensions of dynamic stability DS, to find the correlation between them, to determine whether there is any abnormal data through the residual plot, to see whether the regression model can satisfy the correlation requirements of the original data, and then finally get the regression equation and establish the model.

Take the ternary primary model as an example. Firstly, the ternary linear regression between the fractal dimensions was analyzed, and the ternary linear regression model on the dynamic stability was established. Residual plots of dynamic stability versus fractal dimension were plotted by computer simulation software to check for anomalous data. The regression analysis was performed after removing the outliers to obtain a more accurate regression model.

As can be seen from Fig. 1, the residuals of all the data are close to zero, and the confidence interval of the residuals is zero. The confidence intervals contain zeros, indicating that the regression model can satisfy the original data. A three-way linear regression analysis was performed to obtain a model of dynamic stability. The regression coefficients of the obtained regression equation $R^2 = 0.999$, from the formula. $DS = 2349.96 - 88704.5D - 22255.2D_c + 13900.5D_f$, regression coefficient $R^2 = 0.999$, regression effect is very significant[11].

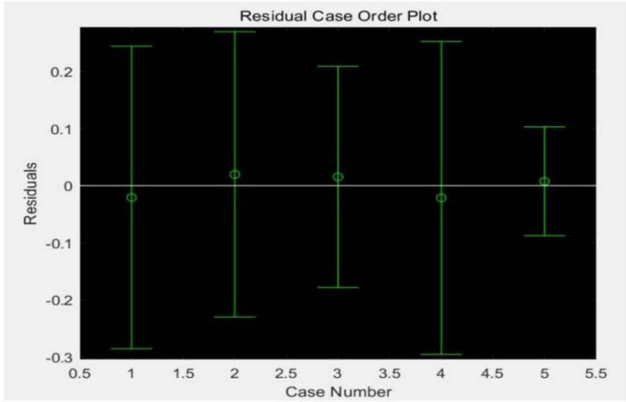


**Fig. 1** SMA-13 residual plot dynamic stability and fractal dimension parameters.

## 4. Comparison of high temperature prediction models

The three-dimensional primary model is used as an example to model the dynamic stability and fractal dimension parameters, which model (three-dimensional primary model, one-dimensional quadratic model, and two-dimensional primary model) has better dynamic stability correlation and higher prediction accuracy, and the results of the model comparison are shown in Table 8.

**Table 8.** SMA-13 dynamic stability correlation model ratio selection.

| Model types | Model expression | Regression coefficient | Merits and demerits |
|---|---|---|---|
| Three-variable linear equation | $DS=2349.96-88704.5D-22255.2D_c+13900.5D_f$ | 0.9990 | Higher regression coefficient and more comprehensive analysis of influencing parameters. |
| Two-variable linear equation | $DS=3258.70-2541.60D+4960.85D^2$ | 0.8064 | High regression coefficient and single analysis of influencing parameters. |
| | $DS=1623.78-1163.55D_f+2088.73D_f^2$ | 0.1515 | Low regression coefficient and single analysis of influencing parameters. |
| | $DS=2076.078-2182.27D_c+58205.39D_c^2$ | 0.9955 | Higher regression coefficient and single analysis of influencing parameters. |
| Two-variable linear equation | $DS=-50998.14-13400.87D-6857.10D_c$ | 0.8119 | High regression coefficient and more comprehensive analysis of influencing parameters. |
| | $DS=-35227.23+18544.27D-3177.23D_f$ | 0.6669 | Regression coefficients are average and more comprehensive analysis of influencing parameters |
| | $DS= 11995.04-4118.05Dc-223.43D_f$ | 0.7751 | Regression coefficients are average and more comprehensive analysis of influencing parameters |

## 5. Conclusion

In this paper, through the high temperature performance test and fractal theory, the related fractal dimension is obtained, and the fractal prediction model of road performance is established. After model selection, it is found that the one-dimensional quadratic linear model : $DS=2349.96-88704.5D-22255.2D_c+13900.5D_f$ of the high temperature performance of SMA-13 cold-patched asphalt mixtures is better than other models, and it is adopted. Meanwhile, through the correlation analysis between high temperature performance and fractal dimension, it is found that the factors with higher correlation with high temperature performance in the optimal model selected in this paper are D, and $D_c$ , which indicates that the fractal dimension of gradation and the fractal dimension of coarse aggregate have a greater influence on the high temperature performance of the mixture, and the fractal dimension of fine aggregate has a smaller influence.

This article optimizes and improves the road performance of SMA-13 cold patched asphalt mixture on the basis of predecessors, making it suitable for the use of heavy-duty traffic asphalt pavement. It also establishes a relevant road performance prediction model based on experiments, fractal theory as the theoretical basis, and computer simulation software as the tool. However, due to limited time and energy, there are still some shortcomings in this article that cannot be further discussed in depth. The further research can be conducted on the types, proportions, and sequences of additives.

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