Research on Asphalt Pavement Uniformity Evaluation Based on Road Surface Temperature

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Abstract

The correlation between the inhomogeneity of asphalt pavement and the surface temperature was established by numerical simulation. The feasibility of the asphalt pavement uniformity detection based on surface temperature was verified. And it was further verified by field test. The numerical analysis shows that the road surface temperature can effectively reflect the difference in porosity of the asphalt pavement, and the site test verifies that porosity of asphalt pavement has a good correlation with the temperature change rate of asphalt pavement surface. Road surface temperature can effectively evaluate the inhomogeneity of asphalt pavement.

Keywords

Inhomogeneity, finite element, porosity, surface temperature, infrared.

1. Introduction

Uniformity of asphalt pavement directly affects the mechanical properties and service life of pavement. When the actual pavement parameter value does not match the design value, it can be defined as inhomogeneous state of the asphalt pavement, including the aggregate gradation, binder content, porosity, thickness and other mechanical and road performance parameters. Inhomogeneous of asphalt pavement will lead to a decline in road performance and fatigue life. As a kind of material with high temperature sensitivity, the asphalt mixture shows a difference in temperature when there is unevenness locally, based on which, the uniformity can be judged and evaluated. This paper starts from the perspective of road surface temperature, analyzes and validates the feasibility of the evaluation method of asphalt pavement uniformity based on surface temperature from two aspects: numerical simulation and site testing.

2. Feasibility Analysis Based on Numerical Model

The factors affecting the pavement surface temperature are not only related to external influences such as temperature, sunshine, and wind speed, but also closely related to the thermodynamic parameters of the pavement structure and materials. Although it is impossible to control external factors, it can control the internal factors that affect the temperature change of asphalt pavement. Inhomogeneity directly reflects the uneven of density, and the density is closely related to the porosity [1]. The change of porosity will inevitably lead to the change of the thermal parameters of pavement, which will cause the difference of surface temperature. By using ABAQUS finite element software to built a 2D finite elelment model of asphalt pavement with different porosity, which establish certain external conditions (solar radiation, sunshine duration and wind speed) and different porosity to simulate the uneven state.

2.1 Numerical Models and Related Parameters

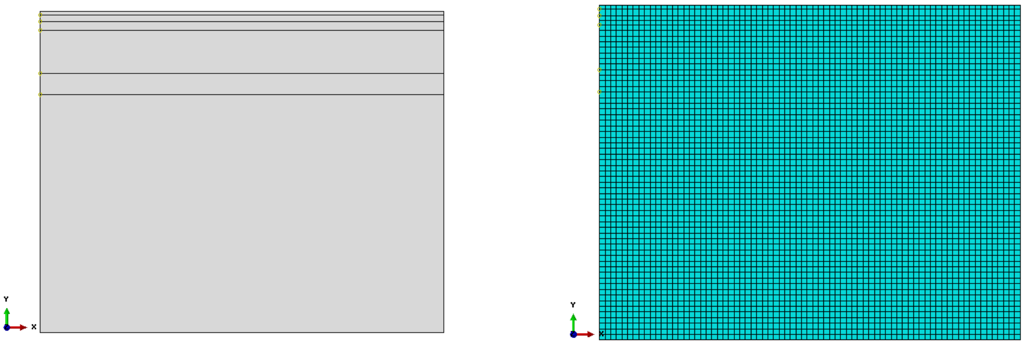
2.1.1 Numerical Model

The pavement structure used in the model is shown in the figure:

Modified asphalt AC-13	4cm
Modified asphalt AC-20	6cm
Heavy traffic asphalt AC-25	8cm
Semi-rigid base	40cm
Lime Stabilized Soil Base	20cm
Soil base	

Figure 1. Structure of Asphalt Pavement with Semi-Rigid

With reference to the relevant temperature field modeling methods [2-4] in China and abroad, a 2D finite element model with a length of 3.75 m and a total thickness of 3 m was established. The specific conditions are shown in Figure 2.



a）Geometric Model b) Model Meshing

Fig. 2 Analysis Model of Pavement Temperature Field

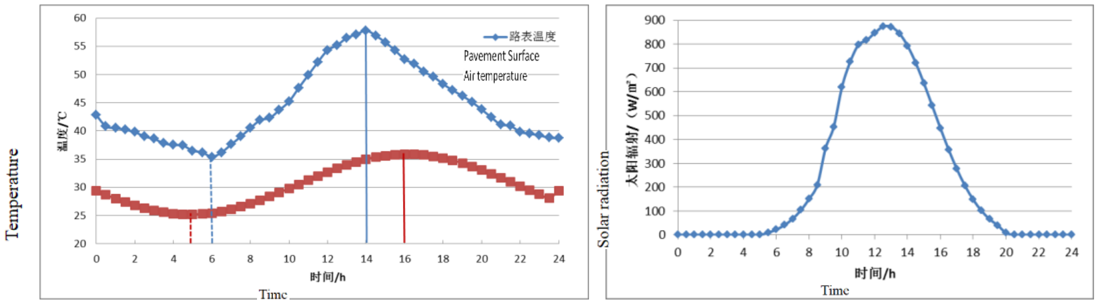
The model makes the following assumptions [5-8]: ① The pavement surface is contaminated by both solar radiation and air heat, and long-wave radiation is emitted to the atmosphere; ② both sides of the model and the lower boundary, no heat exchange; ③ the material is isotropic, homosexual.

2.1.2 Thermodynamic Parameters of Material

① Weather parameters

Typical weather thermal parameters (surface temperature, atmospheric temperature, and solar radiation) required for the acquisition of the model are shown in figure 3.

As can be seen from figure 3, the atmospheric temperature and the temperature of the surface change approximately sinusoidal distribution within 24 hours, and the solar radiation amount is approximately normal distribution; the pavement surface temperature is significantly greater than the atmospheric temperature value, and the surface temperature extreme value appears at 16:00. The extreme value of atmosphere appeared at 14:00, and the extreme value of solar radiation appeared at 12 o'clock.



a) 24h Represents Temperature and Surface Temperature b）24h Solar Radiation

Fig. 3 Thermodynamic Parameters of the Weather

② Thermal parameters of pavement material

The thermodynamic parameters of materials for each structural layer of the pavement are shown in the following table:

Table 1. Thermodynamic Parameters

Thermodynamic parameters	Type of asphalt pavement			Semi-rigid base	Lime Stabilized Soil Base	Soil base
	AC-13	AC-20	AC-25			
density /（kg/m³）	2390	2450	2490	2200	2100	1800
Thermal Conductivity /(J/(m h ℃))	4800	4800	4800	5620	5150	5620
Heat capacity /(J/(kg ℃))	920	920	920	910	915	1040
Solar radiation absorption rate	0.9	-	-	-	-	-
Road surface emissivity	0.81	-	-	-	-	-
Constant of Stefan-Boltzmann /(J/(h ㎡K⁴))	2.0411×10^{-4}	-	-	-	-	-

It was determined by experiments that the optimum asphalt ratio is 5%, which was determined by experiments, and the designed target porosity is 4.5%; simulate different in-homogeneities by using different porosity (2%, 4%, 6%, 8%, and 10%). It is clear from the relevant research that the change of the porosity will lead to the change of thermal conductivity and density of the material, and the value of the corresponding relationship in Table 2 will be used in the modeling and analysis.

Table 2. The Relationship between Thermal Conductivity and Porosity of Asphalt Mixture

porosity	2%	4%	6%	8%	10%
Thermal Conductivity /(J/(m h ℃))	5076	4853	4637	4428	4226
Mixture density /(kg/m^3)	2484	2433	2382	2332	2281

By substituting thermal parameters into the finite element model, the variation of the pavement surface temperature can be obtained when different porosity is provided.

2.2 Numerical Simulation and Result Analysis

The 2D finite element model established by the finite element software was used to calculate the variation of the pavement surface temperature within one day at different porosity. The wind speed is $2.6m/s$, the total solar radiation is $28.79\times10^{6}\,J/m^{2}$, and the solar radiation absorption rate of road surface is 0.9.

The calculation result is shown in Figure 4:

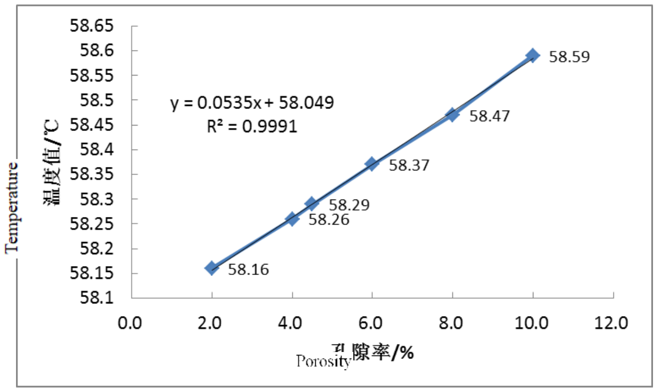


Fig. 4 Calculation Results of Road Surface Temperatures at Different Porosity

From the above figure, we can see that with the same conditions of solar radiation, thermal convection and long-wave radiation, the maximum temperature of different porosity shows an approximately linear increase with the increase of the porosity. The reason is that with the increase of porosity, the proportion of air in pavement is increase. Since the thermal conductivity of air is much smaller than that of asphalt and stone, the overall thermal conductivity of the mixture decreases, and the surface layer under the same external conditions is downward. The ability to transfer heat decreases, more heat accumulates on the road surface, resulting in a higher temperature where the porosity is large. It can be seen that the surface temperature can reflect the homogeneity of the mixture, so the road surface temperature can be used to evaluate the uniformity of the asphalt pavement.

3. Field Test Study

The numerical modeling analysis shows that the evaluation of the homogeneity of asphalt pavement based on surface temperature is feasible. This section is to demonstrate and test the method by site test.

3.1 Test Plan

Taking into account the fact that the actual construction can not be different in the number of times of compaction, so using the same gradation of aggregates and asphalt-aggregate ratio, change the quality of the specimens during roller compaction to obtain specimens with different voidage. When molding the specimens, calculate the quality of the mixture required by different density, and use the wheel rolling method to form six blocks asphalt plates with 300mm long, 300mm wide, and 50mm thick for temperature testing. And then the porosity of the specimens were analyzed.

The six specimens with different porosity are placed in an open and unobstructed space to ensure that they are fully exposed to sunlight. FLUKE Ti50 infrared imager was used to collect the temperature data of the surface of each specimen. During data collection, considering that only the surface of the actual road is affected by temperature and radiation, and the side does not directly exchange heat with the outside, only the temperature data within the fixed area of the center position of the specimen is collected. The specific situation is shown in Figure 5.

a) FLUKE Ti50 Infrared Imager b) Sample Arrangement

c) Photographed Area d) Solar Radiation Data Acquisition

Fig. 5 Test site and Instrument

Choosing cloudless day for data collection. Before the sun comes out, placing the specimens in the order to the test site. Using infrared tester to collect the surface temperature data every 10 minutes. Recording the real-time solar radiation value measured by the solar radiation instrument until the sun dips below the horizon.

3.2 Analysis of Test Results

3.2.1 Data Processing

In order to eliminate the influence of the different initial temperature of each test piece, the change rate of the temperature per unit time is used to characterize the different porosity under the same external environment, and its own temperature change with the voidage rate. The temperature change rate of the test piece is calculated according to formula (1):

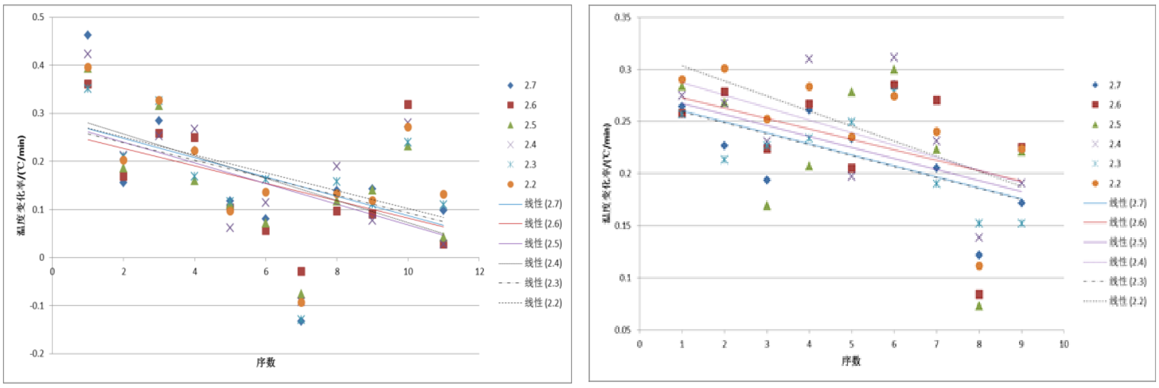
$$RTC = \frac{\Delta T}{\Delta t} = \frac{T_b - T_f}{t_b - t_f} \tag{1}$$

RTC is the rate of temperature change; ΔT is the temperature difference; T_b and T_f are measured temperature value; Δt is the time difference; t_b and t_f are the moment of measuring.

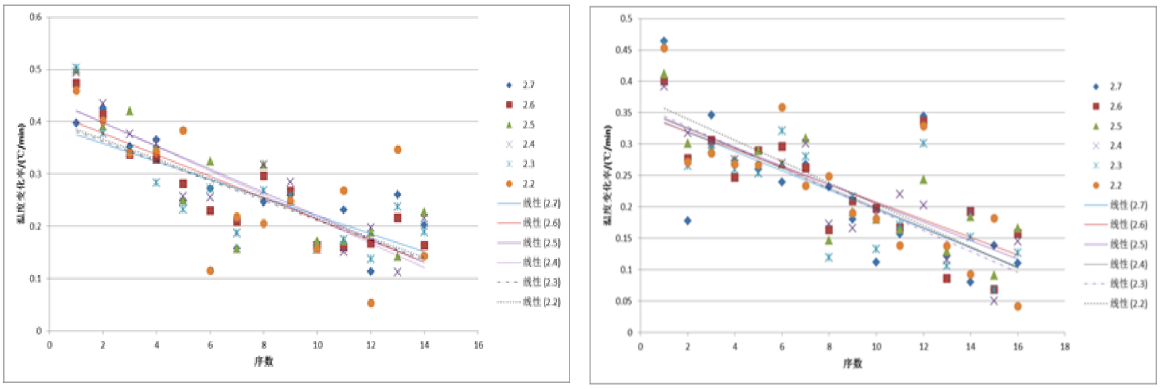
3.2.2 Analysis of Test Data

During the morning time, solar radiation is the main influencing factor, and the heating rate is faster. It good to extand the difference of the specimens with different porosity. Therefore, during the comparative analysis of the temperature change of the specimens with different voidages, the data collected in the morning is best for analysis.

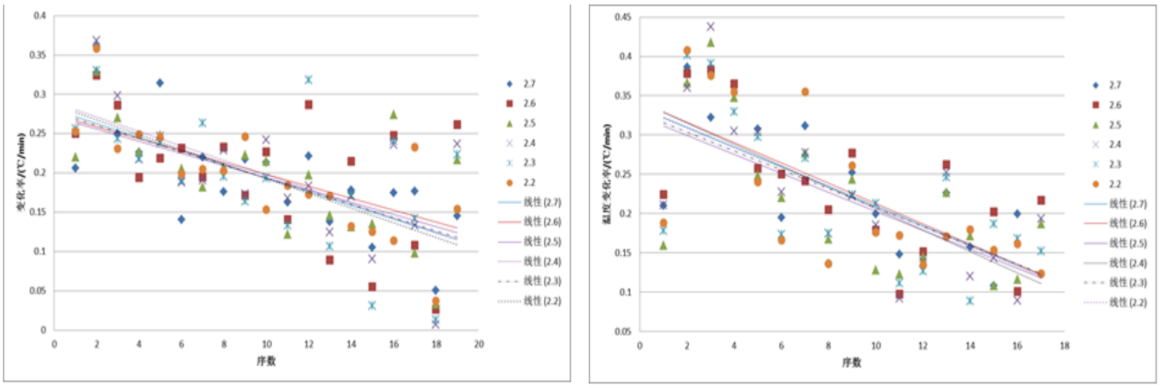
Due to the influence of artificial and actual environmental differences in the test process, the test results will have a certain degree of volatility, but this volatility will be overcome in a large number of repetitive tests, showing a statistically regularity. The specific situation is shown in Figure 6.



a) May 4 b) May 7



c) May 12 d) June 18



e) June 25 f) June 27

Fig. 6 Temperature Change Rate of Specimens with Different Porosity

It can be seen that there is a certain difference in the temperature change rate of the specimens with different porosity. In order to further clarify and quantify the effect of different voidages on the temperature change rate, regression equations are obtained (as shown in Table 3), and then the slopes of the regression equations are compared one by one, shown as the table 3, so that the final sorting to all specimens can be made.

From the ranking results in Table 3, it can be seen that due to the different test time, external conditions, and test conditions, there is a great deal of discrepancies in the sorting of different dates. In order to finally determine the order of temperature change rate of the test pieces, statistical results are used. Comparing the temperature change rate of the specimens one by one and counting the number of specimens if it is larger than other specimens, when two results are equal, take 0.5. The specific results are shown in Table 4.

Table 4. Regression Equation of Temperature Change Rate of the Specimens with Different Voidage

Date **specimen**	May 4	May 7
2.2	y = -0.0231x + 0.3036	y = -0.0144x + 0.3178
2.3	y = -0.0182x + 0.275	y = -0.0106x + 0.2695
2.4	y = -0.0186x + 0.2879	y = -0.012x + 0.299
2.5	y = -0.0216x + 0.2836	y = -0.0106x + 0.2779
2.6	y = -0.0182x + 0.264	y = -0.01x + 0.283
2.7	y = -0.0201x + 0.2879	y = -0.0106x + 0.271
Sorting	**2.2＞2.5＞2.7＞2.4＞2.3≈2.6**	**2.2＞2.4＞2.5≈2.7≈2.3＞2.6**

Date **Specimen**	May 12	June 18
2.2	y = -0.0188x + 0.4041	y = -0.0169x + 0.3738
2.3	y = -0.0188x + 0.3999	y = -0.0166x + 0.361
2.4	y = -0.0231x + 0.4444	y = -0.0158x + 0.357

2.5	y = -0.0222x + 0.4423	y = -0.0149x + 0.3544
2.6	y = -0.0205x + 0.4185	y = -0.014x + 0.3474
2.7	y = -0.0173x + 0.3928	y = -0.0154x + 0.3497
Sorting	**2.4＞2.5＞2.6＞2.2≈2.3＞2.7**	**2.2＞2.3＞2.4＞2.7＞2.5＞2.6**

Date / Specimen	June 25	June 27
2.2	y = -0.0094x + 0.2866	y = -0.0126x + 0.3344
2.3	y = -0.0084x + 0.2771	y = -0.0121x + 0.3279
2.4	y = -0.0091x + 0.2892	y = -0.0136x + 0.3424
2.5	y = -0.0077x + 0.2712	y = -0.0121x + 0.3236
2.6	y = -0.0076x + 0.274	y = -0.0129x + 0.3421
2.7	y = -0.0087x + 0.2805	y = -0.0125x + 0.3346
Sorting	**2.2＞2.4＞2.7＞2.3＞2.5＞2.6**	**2.4＞2.6＞2.2＞2.7＞2.5≈2.3**

Table 4. Comparison Results of Temperature Change Rate of Specimen

Specimen	**2．2**	**2．3**	**2．4**	**2．5**	**2．6**	**2．7**
2．2	－	5．5	4	5	4	6
2．3	0．5	－	1	3	3．5	2．5
2．4	2	5	－	5	6	5
2．5	1	3	1	－	5	2．5
2．6	2	2．5	0	1	－	2
2．7	0	3．5	1	3．5	4	－

Table 4 shows that specimen 2.2 is the largest and specimen 2.6 is the smallest. When just considere temperature change rate, the order of each specimens is: Specimen 2.2> Specimen 2.4> Specimen 2.7> Specimen 2.3≈Specimen 2.5 >Specimen 2.6.

In order to further determine the ordering of specimen 2.3 and 2.5, pavement surface texture depth and porosity were introduced to perform auxiliary judgment. See Table 5 for details:

Table 5. Test Result of Surface Texture Depth and Porosity

Specimen	surface texture depth（mm）	porosity
2.2	2.6408	5.745
2.3	2.0219	4.985
2.4	1.4913	5.163
2.5	1.4189	4.868
2.6	1.6796	4.710
2.7	2.1028	5.272

From the result of table 5 and the foregoing analysis, the result of sort according to surface texture depth, porosity, and temperature, are shown as follows:

By surface texture depth:

Specimen 2.2> Specimen 2.7> Specimen 2.3> Specimen 2.6> Specimen 2.4> Specimen 2.5

By porosity:

Specimen 2.2> Specimen 2.7> Specimen 2.4> Specimen 2.3> Specimen 2.5> Specimen 2.6

By temperature change rate:

Specimen 2.2> Specimen 2.4> Specimen 2.7> Specimen 2.3≈ Specimen 2.5> Specimen 2.6

Analyzing the sort by temperature change date, the porosity of specimen 2.4 is smaller than that of specimen 2.7, and the temperature change rate should be smaller than that of specimen 2.7, but the value of specimen 2.4 is larger than that of specimen 2.7. Combined with the surface texture depth data and porosity data, we can see that although the porosity of specimen 2.4 is smaller than that of test piece 2.7, the depth of surface structure is much smaller than that of test piece 2.7. This means that the surface structure of specimen 2.4 is more dense and will be with Higher thermal conductivity, but because of the smaller thermal conductivity of the larger void ratio, a large amount of heat is concentrated on the surface layer, which leads to a rapid heating

Based on the above analysis, the order of the final surface temperature change rate of the six specimens is: specimen 2.2> specimen 2.7> specimen 2.4> specimen 2.3> specimen 2.5> specimen 2.6. This conclusion is consistent with the regularity of numerical simulation.

4. Conclusion

In this paper, the correlation between the inhomogeneity of asphalt pavement and the surface temperature was established by numerical simulation, and the feasibility of the asphalt pavement uniformity detection based on the surface temperature was verified. And the results were further verified by field test verification.

(1) The thermodynamics finite element model of asphalt pavement with different porosity is established. It is determined that under the same external conditions, the maximum surface temperature value increases approximately linearly with the increase of porosity. It is feasible to evaluate the asphalt pavement uniformity by using surface temperature;

(2) Determined the site test data processing plan:

The concept of temperature change rate in unit time is proposed to characterize the effect of the specimen with different porosity under the same external environment, and overcome the influence of the initial temperature difference of the specimen on the result.

(3) Determining the relationship between porosity and surface temperature. The measured data showed that porosity characterizing the inhomogeneity of asphalt pavement matches well with the surface temperature change rate of the specimen.

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2. Henan Provence Science and Technology Department Major Project, No.:172102310253.

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