Study on icing mechanism of porous asphalt pavement

Jianguang Xie \textsuperscript{1a}, Zhaoxin Wang \textsuperscript{1b}, Zhanqi Wang \textsuperscript{1c}

\textsuperscript{1} Civil and airport engineering, Nanjing University of Aeronautics and Astronautics, Nanjing, Jiangsu, 211106, China
\textsuperscript{b}email: 15651648073@163.com, \textsuperscript{c}email: wangzq911201@nuaa.edu.cn
\textsuperscript{a}Corresponding author’s e-mail: \textsuperscript{a}email: xiejg@nuaa.edu.cn

Abstract: Cold weather influences most parts of China in winter. Pavements are easy to freeze, and the frozen pavements can affect traffic safety and reduce traffic efficiency. For porous asphalt pavement, low temperature has more serious effect on it and it is easier to freeze. The paper takes porous asphalt pavement as the research object, simulates its freezing phenomenon in winter, and measures the ice thickness and freezing depth. The freezing process of porous asphalt pavement is deduced.

1. Introduction

Winter in northern China can last for a long time, the climate is cold and the temperature is low. Low temperatures are also seen in southern areas under the influence of the monsoon. The phenomenon of pavement freezing is more common in our country. The frozen pavement can make the vehicle easy to skid, cause drivers to dazzle and reduce driving safety. In order to improve the highway operation efficiency and reduce the traffic accident rate under different weather such as rain and snow in winter, it is necessary to adopt appropriate means or measures to remove snow and ice on the road surface \cite{1}.

The porous asphalt pavement (PAC) adopts open gradation structure, and the void can reach 15-20\%. Porous asphalt pavement has good drainage performance and can obviously improve the driving performance of vehicles in rainy days. In addition, porous asphalt pavement also has good ecological effects, which can alleviate the urban heat island effect, replenish groundwater and reduce traffic noise \cite{2}. However, because of higher void, the thermal conductivity of porous asphalt pavement is low. The temperature of porous asphalt pavement is lower than dense graded pavement, leading to earlier and more frequent freezing on porous asphalt pavement. Therefore, how to avoid or alleviate freezing of porous asphalt pavement has become an important part of the promotion of porous asphalt pavement \cite{3}.

The paper takes porous asphalt pavement as the research object, measures the ice thickness and the frozen depth with ice sensor or other appropriate means under different influencing factors. With the analysis of experimental data, the freezing mechanism of porous asphalt pavement is clarified.

2. Making specimen

Marshall test piece is made for freezing experiment to complete the paper. A common gradation of PAC—PAC-13 was used to make the specimens. To determine the gradation of mixture, the target void needs to be selected firstly, the empirical formula (1) for the void of asphalt mixture is used to determine the initial gradation, the void of porous asphalt pavement is greatly affected by the pass rate of 4.75mm and 2.36mm mesh, the pass-rate of the 4.75mm and 2.36mm screens in the initial grading...
requires fine-tuning, and the gradation of asphalt mixture with different voids is determined finally. Six gradations are selected in this paper. The six gradations are shown in the table 1. The gradation curve shows an "S" shape, indicating that the intercalation between aggregates is good. After the gradation is determined, the optimal oil-stone ratio of each gradation is determined by the Schellenburg leakage loss experiment.

\[ y = 0.2292 + 0.0005P_{13.2} - 0.00013P_{9.5} - 0.00097P_{4.75} - 0.0029P_{2.36} - 0.0001P_{0.075} \]  

(1)

**y** —— void;

\[ P_n \] —— the pass rate of the aggregate with N (mm)mesh size.

| screen | 16  | 13.2 | 9.5 | 4.75 | 2.36 | 1.18 | 0.6 | 0.3 | 0.15 | 0.075 |
|--------|-----|------|-----|------|------|------|-----|-----|------|-------|
| gradation 1 | 100 | 92.7 | 56.8 | 16.7 | 10.4 | 7.9  | 6.6 | 5.2 | 4.5  | 3.8   |
| gradation 2 | 100 | 95.0 | 65.0 | 25.0 | 16   | 14.0 | 11.0| 9.0 | 6.0  | 4.0   |
| gradation 3 | 100 | 95.0 | 67.5 | 26.5 | 18.5 | 14.3 | 10.0| 8.0 | 6.0  | 4.0   |
| gradation 4 | 100 | 95.0 | 70.0 | 28.0 | 21   | 14.5 | 10.5| 9.0 | 6.0  | 4.0   |
| gradation 5 | 100 | 92.7 | 56.8 | 14.0 | 9.5  | 7.0  | 5.0 | 4.0 | 3.8  | 3.5   |
| gradation 6 | 100 | 95.0 | 45.0 | 10.0 | 8.0  | 7.0  | 6.0 | 5.0 | 4.0  | 3.0   |

Table 1. gradation of PAC-13

| gradation 1 | gradation 2 | gradation 3 | gradation 4 | gradation 5 | gradation 6 |
|-------------|-------------|-------------|-------------|-------------|-------------|
| 4.80%       | 4.90%       | 4.63%       | 5.00%       | 3.73%       | 3.62%       |

Two specimens were made for each grade. The height of Marshall test piece is generally required to be 63.5±1.3mm, and the thickness of the upper and middle surface layer of the pavement is generally 10cm, so the height of the test piece is also selected to be 100mm. The height of the test piece can be adjusted by adjusting the quality of the mixture during production.

3. Freezing experiment of PAC

3.1. Surface freezing experiment of PAC

The paper analyzes the factors that affect icing, and selects three factors for experiments: rainfall intensity and void. The experiment was carried out at -30℃. The specimen was placed under the experimental temperature in advance, so that the surface temperature of the specimen would be close to the experimental temperature. Then water was sprayed on the surface of the specimen to simulate rainfall with the rainfall intensity of 0.6mm/min, 1.2mm/min, 1.8mm/min and 2.4mm/min for 20 minutes. After spraying, continue to freeze at experimental temperature for 5 minutes. After freezing, measure the ice thickness on the surface of the specimen by ice sensor. The average value of the measured results of the two specimens in the same group was taken as the final result. Combined with the experimental results, the effects of temperature, rainfall intensity and void on ice thickness were analyzed:

(1) The relationship between rainfall intensity and ice thickness

The relationship between ice thickness and rainfall intensity is shown in the figure 1.
Figure 1. Curve of ice thickness with rainfall intensity

In the experiment, it is observed that the ice thickness increases with the increase of rainfall intensity. The ice thickness of specimens with different voids increased to the same extent as the rainfall intensity, with an increase rate of about 11-19%. In some samples with high voids, the increase of ice thickness can even reach 50% under low rainfall intensity. The increase of rainfall intensity will increase the amount of water on the pavement, which will aggravate the freezing of the road and increase the thickness of the ice.

(2) The relationship between void and ice thickness

The relationship between ice thickness and void is shown in the figure 2.

Figure 2. Curve of ice thickness with void

In the experiment, it is observed that the ice thickness increases with the increase of void. The ice thickness of the specimen with the largest voids increases by about 20-30% compared with that of the specimen with the lowest voids. The specimens with higher voids have lower thermal conductivity and lower surface temperature, which increases the ice thickness.

3.2. Internal freezing experiment of PAC

The internal freezing experiment and the surface freezing experiment have the same steps. After spraying the water and freezing, the ice on the surface is removed and the mass of the specimen is taken. And the mass of each specimen after freezing in the state of full water is taken, too. The freezing depth inside the specimen is calculated according to Equation (2). The average of the measurement results of the two specimens in the same group was taken as the final result.

\[ D = \frac{m_2 - m}{m_1 - m} H \]  

(2)

D- freezing depth, cm;

\( m_2 \) - mass of the specimen after freezing, g;

\( m \) - mass of specimen, g;
m1 - mass of specimen after freezing in full water condition, g;
H - specimen height, cm.

Combined with the experimental results, the effects of temperature, rainfall intensity and void on freezing depth were analyzed:

1) The relationship between rainfall intensity and freezing depth

The relationship between freezing depth and rainfall intensity is shown in the figure 3.

![Figure 3. Curve of freezing depth with rainfall intensity](image)

The variation of freezing depth with rainfall intensity can be divided into three stages: when the rainfall intensity increases from 0 to 0.6mm/min, the freezing depth increases faster. When the rainfall intensity is between 0.6mm/min and 1.2mm/min, the growth rate of freezing depth begins to slow down. When the rainfall intensity was above 1.2mm/min, it had almost no effect on the freezing depth inside the specimen. After the rainfall intensity increases, the pavement freezes more heavily, and the void is blocked. The rainfall no longer flows into the void, so the freezing depth does not change.

2) The relationship between void and freezing depth

The relationship between freezing depth and void is shown in the figure 4.

![Figure 4. Curve of freezing depth with void](image)

The freezing depth increased with the increase of the void. The freezing depth of the specimen with the largest voids increases by about 11% compared with that of the specimen with the lowest voids. The specimen with higher void has lower thermal conductivity and lower temperature, which increases the freezing depth inside.

### 3.3. Analysis of experimental results

There are some special phenomena in the freezing process of porous asphalt pavement. For example, when the rainfall intensity gradually increases, the freezing depth of porous asphalt pavement begins to increase slowly. As the rainfall intensity increased further, the freezing depth even remained constant. According to the analysis of experimental data, the freezing process of drainage asphalt
pavement is as follows: when the rain falls on the road, some of it flows into internal void and freezes inside the road, while some of it freezes on the road, the ice thickness and freezing depth begin to increase. Ice gradually jams the void of the pavement, and the speed of rain flowing along the void slows down. At this time, the ice thickness continues to increase, while the growth rate of freezing depth begins to slow down because there is no rain inflow inside the pavement. All voids get jammed, only the ice thickness increases while the freezing depth does not increase anymore.

In the experiment, when the rainfall intensity was low, the ice thickness and freezing depth of the specimens with high void were both low. The reason may be that the high void on the road could drain the rain on the pavement faster and reduce the ice thickness and freezing depth\(^\text{[4,5]}\). However, more experimental data are still needed for further verification.

4. Conclusion

The paper used Marshall test piece to start the simulation freezing experiment, the ice thickness and the freezing depth of PAC are measured. The main conclusions are as follows:

1) Temperature, void and rainfall intensity all have effects on the ice thickness. When the temperature was lower, the void was higher and the rainfall intensity was higher, the ice thickness was also thicker.

2) Temperature, void and rainfall intensity also have an effect on freezing depth. When the temperature was lower and the void was higher, the freezing depth was deeper. Rainfall intensity has certain influence on freezing depth, when rainfall intensity increased from 0, the freezing depth begins to increase gradually, but when rainfall intensity increases further, freezing depth increase begins to slow down, when the rainfall intensity reaches a certain value, the freezing depth begin almost not influenced by rainfall intensity increased.

3) After analyzing the experimental data and phenomena, the freezing process of PAC is speculated: when the rain falls on the pavement, part of the rainfalls will flow along the void of the pavement and freeze inside the road, while the other part of the rain will freeze on the road surface. The ice thickness and freezing depth begin to increase. Then ice gradually jams the void of the pavement, and the speed of rain flowing along the void slows down. At this time, the ice thickness continues to increase, while the growth rate of freezing depth begins to slow down because there is no rain inflow inside the pavement. Finally, all void get jammed, only the ice thickness increases while the freezing depth does not increase anymore.

4) According to the icing mechanism of porous asphalt pavement, the icing phenomenon of pavement can be avoided or alleviated by rational design of gradation, taking measures in advance with weather forecast, using active deicing technology and throwing deicing salt.

References

[1] Yang L. (2017) Study on proactive deicing and skid-resisting technology of asphalt pavement with dark ice layer. Wuhan University Of Technology, Wuhan.
[2] Li Q, Li Yd. (2017) Causes Analysis, Prevention & Maintenance Countermeasures to Typical Diseases of Drainage Asphalt Pavement. China Municipal Engineering, 191: 49-51.
[3] Moore, L. M., R. G. Hicks, and D. F. Rogge. (2001) Design, Construction, and Maintenance Guidelines for Porous Asphalt Pavements. In: Transportation Research Record: Journal of the Transportation Research Board, No. 1778, TRB, National Research Council, Washington, D.C., pp. 91–99.
[4] Isening, T., H. Koster, and I. Scazziga. (1990) Experiences with Porous Asphalt in Switzerland. In Transportation Research Record 1265, TRB, National Research Council, Washington, D.C., pp. 41–53.
[5] Houle, K. M. (2008) Winter Performance Assessment of Permeable Pavements. University of New Hampshire, Durham.