УДК 625.855.3 DOI 10.31649/2311-1429-2023-1-43-50

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# THE INFLUENCE OF DEICING SALT ON AIR VOIDS OF ASPHALT MIXTURE UNDER FREEZE-THAW CYCLE

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*The extensive use of deicing salt has not only solved the problem of road icing but also had a serious impact on the pavement, reducing its lifespan. In order to deeply understand the impact of deicing salt on the air voids of asphalt mixture in the northwest climate of China, this paper conducted freeze-thaw cycle tests on AC-13 and AC-16 asphalt mixtures under three different deicing salt solutions and three different low-temperature environments, and analyzed the changes in air voids, meanwhile, the Logistic prediction model was used to evaluate the change characteristics of the air voids. The experimental results showed that the air voids of asphalt mixture increased to varying degrees after multiple freeze-thaw cycles; when the temperature was above its freezing point, no frost heave damage occurred, and the air voids increased slowly; when the temperature was below the freezing point, frost heave damage occurred, causing rapid growth and connection of voids in the mixture, and the air voids increased rapidly; the Logistic model showed a good fit with the observed changes in air voids.*

***Key words:*** *asphalt mixture, freeze-thaw cycle, air voids, deicing salt.*

## Introduction

With the rapid development of society, more and more roads have been paved with asphalt concrete [1-2]. However, as the impact of global climate change intensifies, winter maintenance of roads in cold regions has become an important issue [3]. The main method of winter road maintenance is to spread deicing salt when the road is frozen, but the long-term and excessive use of deicing salt also increases the damage to road materials [4-5].

Air voids is one of the important indicators for evaluating the performance of asphalt mixtures [6]. The size of the air voids directly affects the frost resistance and durability of asphalt mixture, and reducing the air voids appropriately is an effective way to improve their performance. Scholars have conducted some related research on the influence of air voids, JOHN T [7] believes that lower air voids is beneficial for both fatigue life and initial stiffness. Jing Hu [8] found through a study of the internal structure of asphalt mixture that different porosity distributions and shapes have a significant impact on the failure state of asphalt mixture. Yanjing Zhao [9] proved through CT scanning images that non-connected pores in asphalt concrete mainly distribute near the center of the specimen, and connected pores are distributed slightly closer to the outer edge. Tao Ma [10] investigated the influence of structural parameters such as air voids, pore size, and pore distribution on the creep behavior of asphalt mixtures and found that the more and larger the pores, the greater the creep strain of the asphalt mixture, in addition, the uneven distribution of pores in asphalt mixture also has a negative impact on their creep deformation. However, these studies did not consider the variation of porosity under salt dissolution conditions.

On the basis of the special climate in northwest China [11-12], this paper uses collected data on rainfall, air humidity, and temperature between pavement layers to conduct freeze-thaw cycle tests on two types of asphalt mixture with three deicing salt solutions of suitable concentration and in three low-temperature environments. The study aims to investigate the mechanism of the effect of deicing salt on the air voids of asphalt mixtures and to propose corresponding measures to reduce the damage caused by deicing salt to asphalt mixtures, providing a reference for road design and maintenance.

## Experimental materials and methods

In this experiment, KL-90 petroleum asphalt was selected, and its various technical indicators were determined to meet the requirements of the specifications, as shown in Table 1. The technical indicators of the selected coarse and fine aggregates and mineral powder also met the specifications, as shown in Tables 2 - 4.

Table 1

**Technical indexes of asphalt**

| Index | Test Result | Requirement | Test Method |
|---|---|---|---|
| Penetration (25 °C, 100 g.5s)/0.1 mm | 88.5 | 80~100 | T0604 |
| Penetration Index | -0.9 | -1.5~+1.0 | T0604 |
| Softening Point/°C | 49 | ≥45 | T0606 |
| Flash Point/°C | 303 | ≥245 | T0611 |
| Extensibility (15 °C)/cm | 147 | ≥100 | T0605 |
| Density (15 °C)/(g·cm-3) | 1.034 | — | T0603 |
| Dynamic viscosity (60°C)/Pa•s | 153 | ≥140 | T0620 |
| Solubility/% | 99.8 | ≥99.5 | T0607 |

Table 2

**Technical indicators of coarse aggregate**

| Index | Test Result | Requirement | Test Method |
|---|---|---|---|
| Crushed Stone Value/% | 17.6 | ≤28 | T0316 |
| Los Angeles Abrasion Loss/% | 17.5 | ≤30 | T0317 |
| Apparent Particle Density | 2.82 | ≥2.5 | T0304 |
| Solmdness/% | 10.8 | ≤12 | T0314 |
| Water Absorption/% | 1.5 | ≤3 | T0304 |

Table 3

**Technical indicators of fine aggregate**

| Index | Test Result | Requirement | Test Method |
|---|---|---|---|
| Apparent Particle Density | 2.74 | ≥2.50 | T0328 |
| Sand Equivalent/% | 75 | ≥60 | T0334 |
| Solmdness/% | 9.2 | ≤12 | T0340 |
| Mud Content/% | 2.0 | ≤3 | T0333 |

Table 4

**Technical indicators of mineral powder**

| Index | Test Result | Requirement |
|---|---|---|
| Density/(t·m-3) | 2.82 | ≥2.5 |
| Water Absorption/% | 0.88 | ≤1 |
| Hydrophilic Coefficient/% | ≤1 | ≤1 |
| Appearance | No agglomerates | No agglomerates |

For this experiment, two types of dense-graded asphalt mixture, AC-13 and AC-16, were selected. The target gradation curves are shown in Figures 1 - 2.

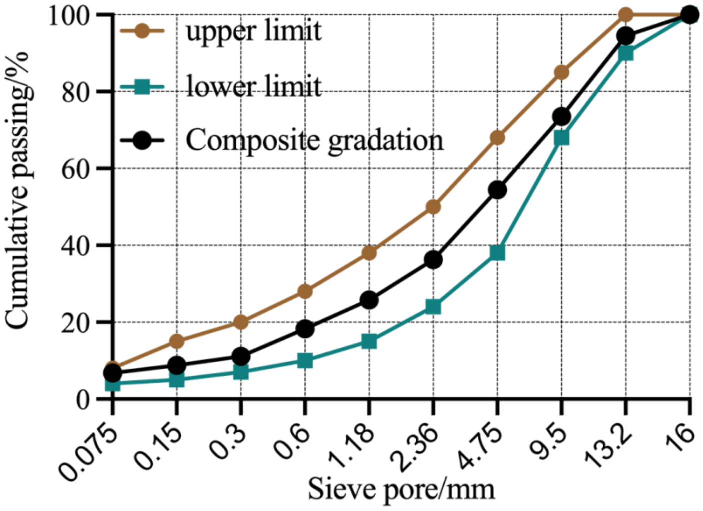


Fig.1 Synthetic grading curve of AC-13

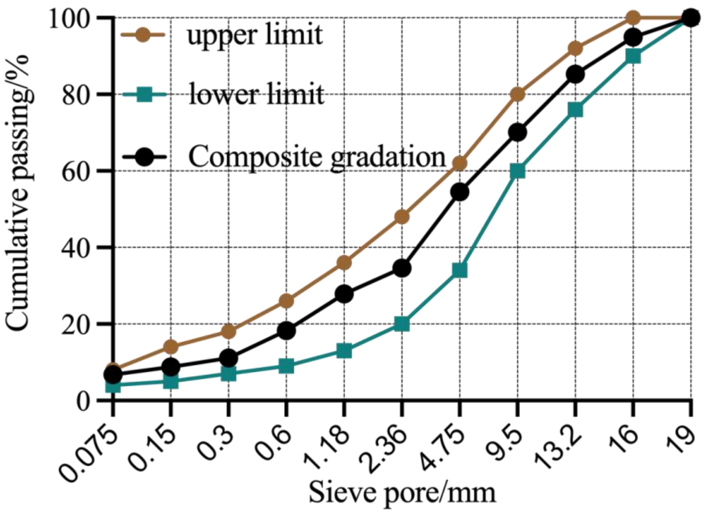


Fig.2 Synthetic grading curve of AC-16

On the basis of considering the deicing effect and economy, the experiment adopted 20% industrial salt (NaCl), 15% urea ($CH_4N_2O$) and 20 % anhydrous ethanol ($CH_2CH_3OH$) as the solutions for the freeze-thaw cycles, respectively. Marshall specimens of two types of gradations, AC-13 and AC-16, were prepared and subjected to freeze-thaw cycle tests with 0, 5, 10, 15, 20, 25, and 30 cycles at temperatures of -5°C, -15°C, and -25°C. Each cycle included immersion in the three solutions for 12 ± 0.5 hours and subsequent placement in the temprature controlled cabinet for 12 ± 0.5 hours. After the completion of the freeze-thaw cycles, the air voids of the asphalt mixture were determined according to the "Standard Test Methods for Bitumen and Bituminous Mixtures for Highway Engineering" (JTG E20-2011).

## Results analysis and discussion

The results of air voids and its growth rate of AC-13 asphalt mixture after freeze-thaw cycles in three different deicing salt solutions and three different low temperature environments are shown in Figure 3.

From Figures 3(a) and 3(b), it can be seen that when the gradation of asphalt mixture is AC-13 and the freezing temperature is -5°C, the air voids corresponding to the three types of deicing salt solutions shows an increasing trend with the increase of freeze-thaw cycles, and the temperature at this time did not fall below the freezing point of the three deicing salt solutions, so the growth rate is slow. Among them, $CH_4N_2O$ has the greatest influence on the air voids, and its corresponding air voids increased by 39.25 % to 6.28 % in the 30th cycle, which no longer meets the air voids requirements of some pavements. NaCl has the second largest influence on the air voids, and its corresponding air voids increased by 19.51 % to 5.39 % in the 30th cycle. $CH_2CH_3OH$ has the smallest influence on the air voids, and its corresponding air voids increased by 13.97 % to 5.14 % in the 30th cycle.

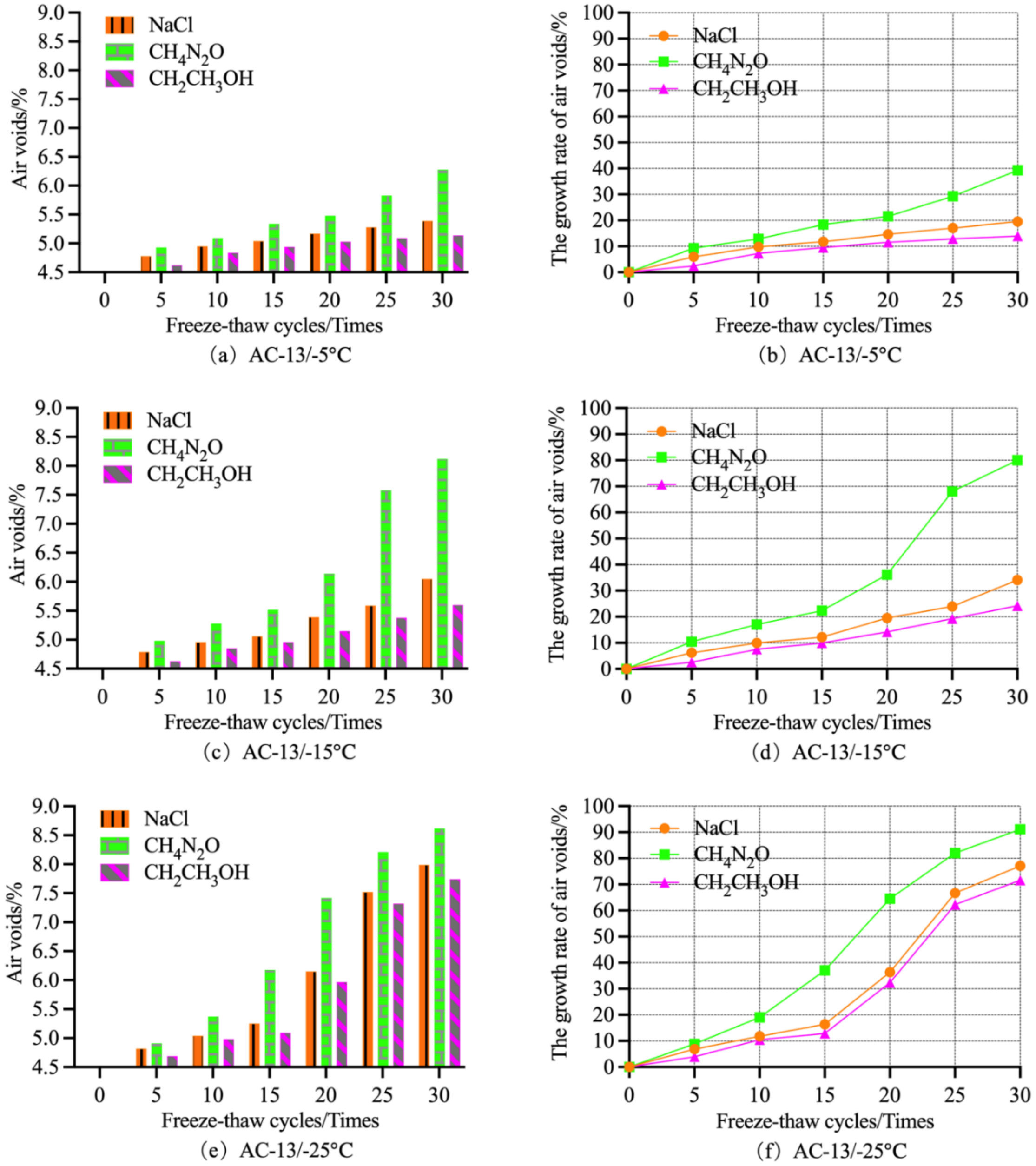


Fig. 3 Variation of air voids with increasing number of freeze-thaw cycles

From Figure 3(c) and 3(d), it can be seen that when the gradation of asphalt mixture is AC-13 and the freezing temperature is -15°C, the air voids of the three types of deicing salt solutions increases with the number of freeze-thaw cycles, and the air voids corresponding to $CH_4N_2O$ starts to increase rapidly from the 20th cycle, with a much higher growth rate than that of NaCl and $CH_2CH_3OH$. At this point, the temperature has dropped below the freezing point of the solution of $CH_4N_2O$, and condensation occurs. In the 30th cycle, the corresponding air voids of $CH_4N_2O$ increased by 80.04%, reaching 8.12 %, which no longer meets the requirements for air voids of road. NaCl has the second largest impact on air voids, and its corresponding air voids increased by 34.15 % in the 30th cycle, reaching 6.05 %. $CH_2CH_3OH$ has the smallest effect on air voids, and its corresponding air voids increased by 24.17 % in the 30th cycle, reaching 5.60 %.

From Figure 3(e) and 3(f), it can be seen that when the gradation of asphalt mixture is AC-13 and the freezing temperature is -25°C, the air voids of the three deicing salts increases with an increase in the number of freeze-thaw cycles. The air voids corresponding to the three deicing salts start to increase rapidly from the 15th cycle, when the temperature is below the freezing point of all three deicing salt solutions, and condensation occurs. Among them, $CH_4N_2O$ has the greatest impact on the air voids, with its corresponding air voids increasing by 91.13 % in the 30th cycle, reaching 8.62 %. The effect of NaCl on the air voids is second, with its corresponding air voids increasing by 77.16 % in the 30th cycle, reaching 7.99 %. The effect of $CH_2CH_3OH$ on the air voids is the smallest, with its corresponding air voids increasing by 71.62 % in the

30th cycle, reaching 7.74 %.

The results of air voids and its growth rate of AC-16 asphalt mixture after freeze-thaw cycles in three different deicing salt solutions and three different low temperature environments are shown in Figure 4.

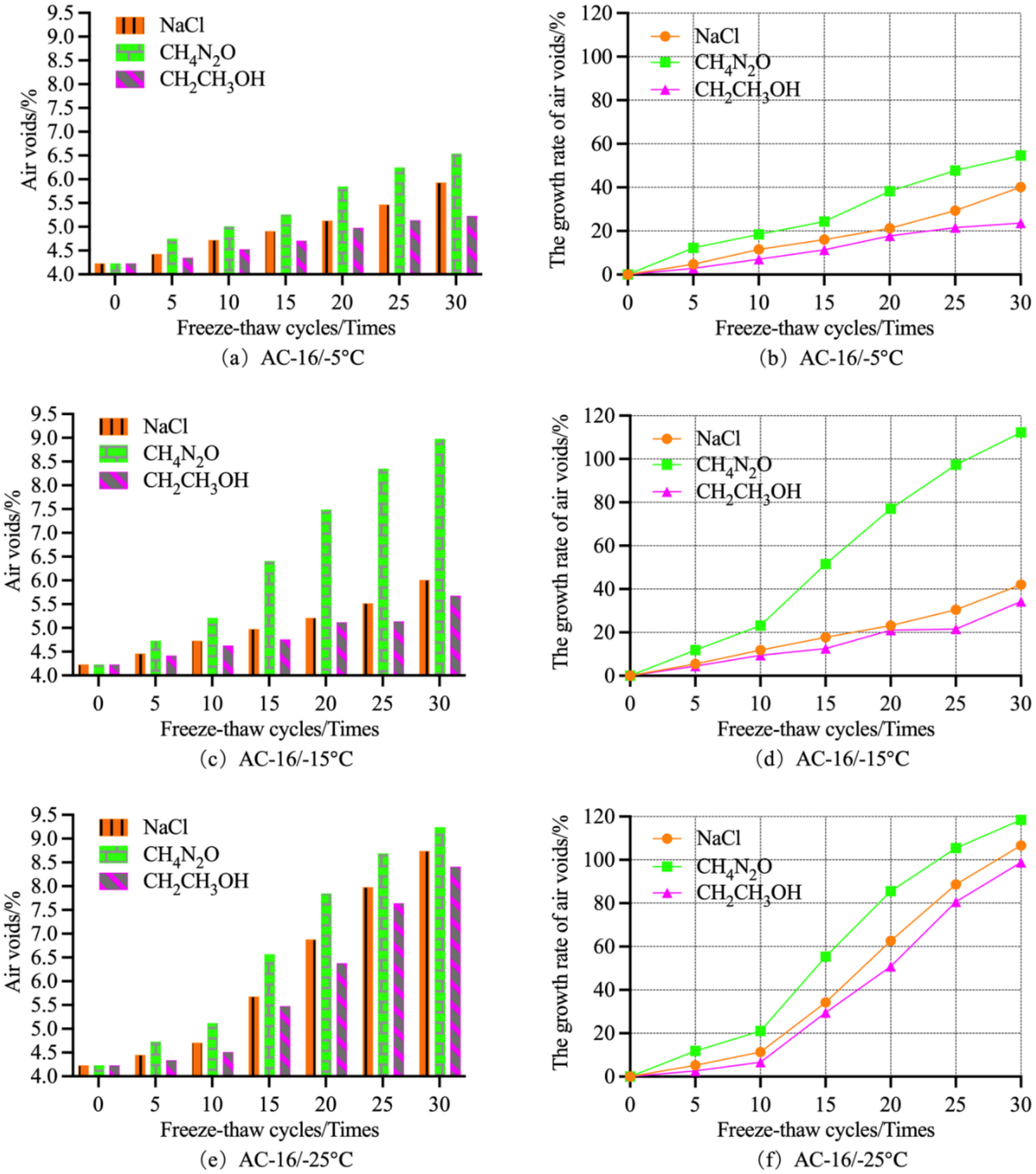


Fig. 4 Variation of air voids with increasing number of freeze-thaw cycles

From Figures 4(a) and 4(b), it can be seen that when the gradation of asphalt mixture is AC-16 and the freezing temperature is -25°C, as the number of freeze-thaw cycles increases, the corresponding air voids for the three types of deicing salts shows a growing trend, and the growth rates are slow as the temperature has not fallen below the freezing point of the three deicing salt solutions. Among them, $CH_4N_2O$ has the greatest impact on the air voids, with an increase of 54.61 % at the 30th cycle, reaching 6.54 %, which no longer meets the requirements of certain pavement. The effect of NaCl on air voids is secondary, with an increase of 40.19% at the 30th cycle, reaching 5.93 %. The effect of $CH_2CH_3OH$ on air voids is the smallest, with an increase of 23.64 % at the 30th cycle, reaching 5.23 %.

From Figures 4(c) and 4(d), it can be seen that for the AC-16 asphalt mixture, when the freezing temperature is -15°C, the air voids corresponding to the three types of deicing salt solutions shows an increasing trend with the increase of freeze-thaw cycles. The air voids corresponding to the solution of $CH_4N_2O$ increases rapidly starting from the 20th cycle, with an increase rate far higher than that of NaCl and $CH_2CH_3OH$, and at this point, the temperature has already dropped below the freezing point of the solution of $CH_4N_2O$, and condensation phenomenon occurs. At the 30th cycle, the corresponding air voids of $CH_4N_2O$ increased by 112.29 %, reaching 8.98 %, which can no longer meet the requirements of the pavement. The impact of NaCl on the air voids is second, and at the 30th cycle, the corresponding air voids increases by 42.08 %, reaching 6.01%. The impact of $CH_2CH_3OH$ on the air voids is the smallest, and at the 30th cycle, the corresponding air voids increases by 34.27 %, reaching 5.68 %.

From Figure 4(e) and 4(f), it can be seen that when the gradation of asphalt mixture is AC-16 and the freezing temperature is -25°C, the air voids of the three types of deicing salts all show an increasing trend with the increase of freeze-thaw cycles, and the air voids of the three types of deicing salts all starts to increase rapidly from the 15th cycle, at which point the temperature is lower than the freezing point of the three deicing salt solutions, and condensation occurs. Among them, $CH_4N_2O$ has the greatest influence on air voids, and its corresponding growth rate reached 118.44 % at the 30th cycle, reaching 9.24 %; NaCl has the second greatest influence on air voids, and its corresponding growth rate reached 106.62 % at the 30th cycle, reaching 8.74 %; $CH_2CH_3OH$ has the smallest influence on air voids, and its corresponding growth rate reached 98.82 % at the 30th cycle, reaching 8.41 %.

Based on Figures 3 and 4, it can be observed from the growth rate of air voids with the increase of freeze-thaw cycles that regardless of whether the freezing point of the deicing salt solution is reached or not, that is, whether it freezes or not, the rate of increase of AC-16 is higher than that of AC-13, moreover, the percentage of fine aggregate in AC-13 is higher than that in AC-16, which means that increasing the percentage of fine aggregate can slow down the speed of void damage and connectivity in asphalt mixtures.

## Prediction models for air voids

In this paper, Logistic prediction model was constructed using two independent variables, x and y, to represent temperature and freeze-thaw cycles, respectively, and the air voids was used as the dependent variable:

$$R_T = \frac{a}{\left[1 + \exp\left(\frac{b - x}{m}\right)\right]\left[1 + \exp\left(\frac{c - y}{n}\right)\right]} + d$$

In this equation, a, b, c, d, m, and n are fitting parameters. $R_T$ is a function that varies with x and y. Through numerical simulation, the Logistic prediction models were fitted under various conditions, and the results are shown in Table 5.

Table 5

**Variance analysis of different influencing factors and air voids**

| Types of Deicing Salt | Gradation | Logistic prediction model | Correlation coefficient $R^2$ |
|---|---|---|---|
| NaCl | AC-13 | $R_T = \frac{26.6}{\left[1 + \exp\left(\frac{21.81 - x}{1.366}\right)\right]\left[1 + \exp\left(\frac{-21.05 - y}{2.298}\right)\right]} + 4.574$ | 0.9379 |
| $CH_4N_2O$ | AC-13 | $R_T = \frac{1.415}{\left[1 + \exp\left(\frac{1.061 - x}{0.7981}\right)\right]\left[1 + \exp\left(\frac{0.8903 - y}{3.712}\right)\right]} + 3.869$ | 0.95 |
| $CH_2CH_3OH$ | AC-13 | $R_T = \frac{9.653}{\left[1 + \exp\left(\frac{16.32 - x}{1.14}\right)\right]\left[1 + \exp\left(\frac{-15.91 - y}{2.069}\right)\right]} + 4.582$ | 0.9357 |
| NaCl | AC-16 | $R_T = \frac{14.31}{\left[1 + \exp\left(\frac{22.41 - x}{1.645}\right)\right]\left[1 + \exp\left(\frac{-22.33 - y}{2.648}\right)\right]} + 4.13$ | 0.9161 |
| $CH_4N_2O$ | AC-16 | $R_T = \frac{3.044}{\left[1 + \exp\left(\frac{0.7394 - x}{0.4165}\right)\right]\left[1 + \exp\left(\frac{1.913 - y}{4.929}\right)\right]} + 2.61$ | 0.9453 |
| $CH_2CH_3OH$ | AC-16 | $R_T = \frac{9.596}{\left[1 + \exp\left(\frac{15.02 - x}{1.175}\right)\right]\left[1 + \exp\left(\frac{-15.8 - y}{2.309}\right)\right]} + 4.24$ | 0.9294 |

From Table 5, it can be seen that, under the coupling effect of multiple factors, the variation of air voids in the asphalt mixture is well correlated with the Logistic model, and the correlation coefficients are all above

0.91. Therefore, the Logistic model can effectively reflect the changing trend of air voids over time.

## Conclusions

By conducting freeze-thaw cycle tests on AC-13 and AC-16 under three different low-temperature environments and three different deicing salt solutions, the following conclusions can be drawn by analyzing the variation of air voids:

(1) The influence of deicing salts on the air voids of asphalt mixtures, from large to small, follows the order of $CH_4N_2O$ > NaCl > $CH_2CH_3OH$.

(2) The erosion resistance of AC-13 is higher than that of AC-16, indicating that increasing the percentage of aggregate can slow down the rate of void damage and connectivity in asphalt mixtures.

(3) When deicing salt solution infiltrates the interior of the asphalt mixture, it can cause erosion damage to the mixture even at temperatures above its freezing point, but frost heaving damage will occur when the temperature drops below its freezing point, which can lead to rapid growth and connectivity of voids in the mixture, seriously affecting the pavement's service life.

(4) The Logistic model shows good correlation with the change of air voids, with correlation coefficients greater than 0.91.

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# ВПЛИВ ПРОТИОЖЕЛЕДНОЇ СОЛІ НА ПОРИСТІСТЬ АСФАЛЬТОБЕТОНУ ПРИ ПОПЕРЕМІННОМУ ЗАМОРОЖУВАННІ ТА ВІДТАВАННІ

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*Широке використання протиожеледної солі ефективно вирішує проблему ожеледиці на дорогах взимку, але її використання негативно впливає на дорожнє покриття, скорочуючи його термін експлуатації. З метою отримання комплексного розуміння впливу протиожеледної солі на коефіцієнт пористості асфальтових сумішей, в умовах наближених до клімату північно-західного Китаю, було проведено дослідження поперемінного заморожування та відтавання. Дослідження проводились на двох видах асфальтобетонних зразків АС-13 і АС-16 які були насичені у трьох різних розчинах протиожеледної солі та піддавались низькотемпературному впливу при -5, -15 та -25°С. Вивчені та проаналізовані зміни коефіцієнта пористості. Застосована логістична модель прогнозування зміни коефіцієнта пористості, для оцінки характеристик довговічності асфальтобетону.*

*Експериментальні результати свідчать про те, що після кількох циклів заморожування та відтавання в обох видів асфальтобетонних зразків спостерігається зростання коефіцієнта пористості різного ступеня. Коли температура перебуває вище точки замерзання, суміші не піддаються пошкодженню від замерзання, і зростання коефіцієнта порожності відбувається відносно повільно. Однак, при температурі нижче точки замерзання, виникають пошкодження, що призводить до швидкого розширення та з'єднання порожнин всередині сумішей, що призводить до значного збільшення коефіцієнта пористості. Крім того, спостерігається чітка кореляція між логістичною моделлю та зміною коефіцієнта пористості встановленого в результаті проведення досліджень.*

*Ключові слова: асфальтна суміш, цикл заморожування-відтавання, повітряні порожнини, протиожеледна сіль.*

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