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EFFECT OF DEICING SALT ON AIR VOIDS AND PERMEABILITY COEFFICIENT OF ASPHALT MIXTURE UNDER DRY-WET CYCLE

ВПЛИВ ПРОТИОЖЕЛЕДНИХ РЕЧОВИН НА ЗАЛИШКОВУ ПОРИСТІСТЬ І ВОДОПРОНИКНІСТЬ АСФАЛЬТОБЕТОНУ ПРИ ПОПЕРЕМІННОМУ НАСИЧЕННІ ТА ВИСУШУВАННІ

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Although the extensive use of deicing salt has solved the problem of road icing in winter and reduced traffic accidents, it has also had a significant impact on the asphalt mixture. Through dry-wet cycle test, this study investigated the change rule of air voids and permeability coefficient of asphalt mixture under the conditions of different gradation, different deicing salt solutions and different dry-wet cycle times, and analyzed the significant indicators of each factor's impact on air voids and permeability coefficient based on variance analysis. The results showed that the air voids and permeability coefficient of AC-13 and AC-16 asphalt mixtures increased to varying degrees after 0, 5, 10, 15, 20, 25, and 30 dry-wet cycles in 20% NaCl, 15% CH_4N_2O, and 20% CH_2CH_3OH solutions, and the air voids and permeability coefficient had a high correlation. Meanwhile, the variance analysis results indicated that gradation was the main factor affecting the air voids and permeability coefficient, followed by the dry-wet cycle times, and deicing salt solutions were the least significant.

Дане дослідження присвячене вивченню впливу протиожеледних речовин на залишкову пористість і коефіцієнт водопроникності асфальтобетонних сумішей за різних умов. Незважаючи на те, що широке використання засобів протиожеледної обробки ефективно вирішує проблеми обмерзання дорожнього покриття взимку і зменшує кількість дорожньо-транспортних пригод, воно водночас має негативні вплив на експлуатаційні властивості асфальтобетонних покриттів.

Завдяки проведенню експериментів з використанням різних видів асфальтобетону, протиожеледних речовин та різної кількості циклів "сухий-мокрий", було вивчено зміни коефіцієнта пористості та коефіцієнта водопроникності асфальтобетонних сумішей. Для оцінки значущості факторів, які впливають на показники залишкової пористості та водопроникності, був використаний дисперсійний аналіз.

Результати досліджень показали, що після 0, 5, 10, 15, 20, 25 і 30 циклів "сухий-мокрий" залишкова пористість і коефіцієнт водопроникності асфальтобетонних сумішей АС-13 і АС-16 показали різний ступінь зміни показників при впливі розчинів, що містять 20% технічної солі (NaCl), 15%

карбаміду (CH_4N_2O) і 20% безводного етанолу (CH_2CH_3OH), відповідно. Крім того, існує значна кореляція між залишковою пористістю і коефіцієнтом водопроникності.

Подальший дисперсійний аналіз показав, що гранулометричний склад є основним фактором, що впливає на коефіцієнт залишкової пористості та коефіцієнт водопроникності, далі йде кількість циклів "сухий-вологий", а вплив розчину протиожеледної рідини є найменш впливовим.

Таким чином, це дослідження всебічно розкриває вплив протиожеледних речовин на коефіцієнт залишкової пористості та коефіцієнт водопроникності асфальтобетонних сумішей за допомогою експериментів та статистичного аналізу. Результати дослідження мають важливе прикладне значення для кращого розуміння впливу протиожеледної речовини на експлуатаційні властивості дорожнього покриття, удосконалення проєктування дорожніх конструкцій та зимового утримання доріг.

Key words: pavement performance, deicing salt, asphalt concrete, dry-wet cycle, air voids, permeability coefficient, deicing salt.

Ключові слова: експлуатаційні властивості дорожнього покриття, протиожеледні речовини, асфальтобетон, "сухий-мокрий" цикл, залишкова пористість, коефіцієнт водопроникності.

Introduction. Asphalt mixture is widely used in road construction, and its quality has a crucial impact on road service life, driving safety, and comfort [1-2]. However, in cold weather during winter, road icing, snow accumulation, and other factors pose significant safety hazards and economic losses to road traffic [3]. Therefore, deicing salt is widely applied in road ice and snow removal, which works by melting ice and snow on the surface and preventing them from freezing again [4]. However, excessive use of deicing salt not only leads to environmental issues such as water pollution, land degradation, and climate change but also causes damage to road materials [5-6].

The size of air voids affects various properties of the asphalt mixture, such as compactness, stability, durability, and water resistance [7]. Generally, a lower air voids can improve the compactness and stability of the mixture, thereby enhancing its shear resistance and durability, and reducing water permeation and damage. ROBERT N et al. [8] found that an increase of 1% in air voids when it exceeds 7% could result in a loss of about 10% in road life. Rui Xiong [9] analyzed the relationship between pore characteristics and splitting strength, and found that the increase of open voids of asphalt mixture had a linear correlation with the decrease of splitting strength under salt corrosion environment. Di Yu [10] conducted a microstructural analysis of asphalt mixtures before and after freeze-thaw cycles, and discovered that the damage source of voids mainly transferred from large voids to small ones. The water permeability coefficient refers to the rate of water passing through the asphalt concrete and reflects its resistance to water infiltration, which is generally highly correlated with the air voids [11]. Although there are many studies on air voids and permeability coefficient, there is relatively limited research on the variation of air voids and permeability coefficient under salt solution conditions.

Taking into account the unique climate of China's northwest region, this paper employs collected data on precipitation, air humidity, and interlayer temperature of the road surface to conduct dry-wet cycle tests on the two gradations of asphalt mixtures using three concentrations of appropriate deicing salt solutions [12-13]. Through this approach, we seek to investigate and analyze the patterns of variation in air voids and permeability coefficient, in order to deepen our understanding of the interaction between deicing salt and asphalt mixture, and to provide a certain reference for road design and maintenance.

Experimental materials and methods. For this experiment, KL-90 petroleum asphalt from the Karamay Refinery in Xinjiang was selected as the asphalt material. It was determined that all of its technical indicators meet the required specifications, as shown in Table 1. The coarse and fine aggregates, as well as the mineral powder, were all sourced from the Wangjiaping quarry in Lanzhou, Gansu Province. Their technical indicators also meet the required specifications, as shown in Tables 2 - 4. Urea (CH_4N_2O) produced by Gansu Liuhua (Group) Co., Ltd., industrial salt (NaCl) produced by Golmud Baojin Chemical Trade Co., Ltd., and anhydrous ethanol (CH_2CH_3OH) produced by Tianjin Beichen Fangzheng Reagent Factory were selected as the three types of deicing salts. All of their technical indicators meet the required specifications.

Table 1

Technical indexes of asphalt

Index	Test Result	Requirement
Penetration (25 °C, 100 g.5s)/0.1 mm	89.2	80~100
Penetration Index	-1.5	-1.5~+1.0
Extensibility (15 °C)/cm	144	≥100
Softening Point/°C	52	≥45
Flash Point/°C	287	≥245
Density (15 °C)/(g·cm-3)	1.033	—
Dynamic viscosity (60°C)/Pa•s	153	≥140
Solubility/%	99.9	≥99.5

Considering the deicing effectiveness and economic efficiency, three solutions containing 20% NaCl, 15% CH_4N_2O, and 20% CH_2CH_3OH were prepared for the dry-wet cycle tests on Marshall samples and rut samples with AC-13 and AC-16 gradations. The samples were subjected to 0, 5, 10, 15, 20, 25, and 30 cycles of dry-wet cycles, with each cycle consisting of immersion in the three solutions for 24 hours followed by air drying for 24 hours. After the dry-wet cycles were completed, the air voids of the mixture samples were measured using the dry-weighing method for the Marshall samples, and the permeability coefficient was determined for the rut samples using the water permeability test, in accordance with the "Standard Test Methods for Bitumen and Bituminous Mixtures for Highway Engineering" (JTG E20-2011).

Table 2

Technical indicators of coarse aggregate

Index	Test Result	Requirement
Crushed Stone Value/%	17.6	≤28
Los Angeles Abrasion Loss/%	17.5	≤30
Solmdness/%	10.8	≤12
Apparent Particle Density	2.79	≥2.5
Water Absorption/%	1.7	≤3

Table 3

Technical indicators of fine aggregate

Index	Test Result	Requirement
Apparent Particle Density	2.71	≥2.50
Solmdness/%	9.2	≤12
Sand Equivalent/%	75	≥60
Mud Content/%	2.1	≤3

Table 4

Technical indicators of mineral powder

Index	Test Result	Requirement
Density/(t·m-3)	2.81	≥2.5
Water Absorption/%	0.88	≤1
Hydrophilic Coefficient/%	≤1	≤1
Appearance	No agglomerates	No agglomerates

Results analysis and discussion. The changes in air voids and its growth rate of the AC-13 asphalt mixture after dry-wet cycle tests in three different deicing salt solutions are shown in Figure 1.

Based on Figure 1, it can be observed that for mixture of AC-13, with an increase in the number of dry-wet cycles, the corresponding air voids for all three deicing salts increases. Among them, CH_4N_2O has the greatest impact on the air voids, with an increase of 34.1% at the 30th cycle, reaching 6.05%, which no longer meets the air voids requirements for certain pavement types; NaCl has the second largest impact on air voids, with an increase of 18.8% at the 30th cycle, reaching 5.36%; the impact of CH_2CH_3OH on air voids is the smallest, with an increase of 13.1% at the 30th cycle, reaching 5.10%.

The changes in air voids and its growth rate of the AC-16 asphalt mixture after dry-wet cycle tests in three different deicing salt solutions are shown in Figure 2.

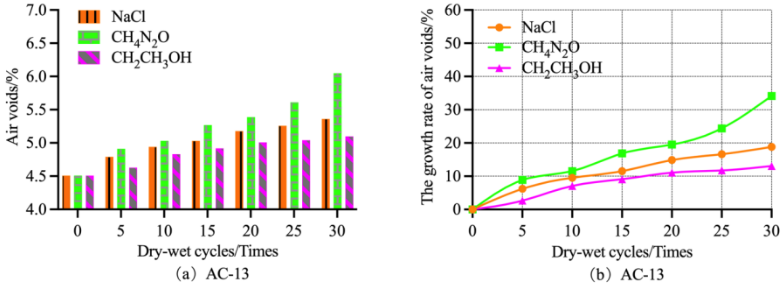

Fig. 1 Variation of air voids and its growth rate of AC-13 with the increase of dry-wet cycles

From Figure 2, it can be seen that for mixture of AC-16, with an increase in the number of dry-wet cycles, the corresponding air voids for all three deicing salts increases. Among them, CH_4N_2O has the greatest impact on air voids, with an increase of 50.8% at the 30th cycle, reaching 6.38%, which no longer meets the air voids requirements for certain pavement types. NaCl has the second largest impact on air voids, with an increase of 39.2% at the 30th cycle, reaching 5.89%; the impact of CH_2CH_3OH on air voids is the smallest, with an increase of 23.8% at the 30th cycle, reaching 5.24%.

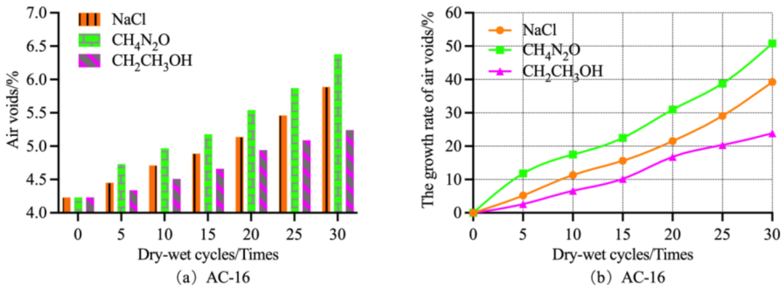

Fig. 2 Variation of air voids and its growth rate of AC-16 with the increase of dry-wet cycles

Comparing Figures 3 and 4, it can be seen that the growth rate of air voids for AC-16 is significantly higher than that for AC-13. This indicates that, in terms of air voids, the impact of the three salt solutions on AC-16 is greater than that on AC-13.

When the gradation is AC-13, the changes in permeability coefficient and its growth rate after dry-wet cycle test under three different deicing salt solutions are shown in Figure 3.

From Figure 3, it can be observed that when the gradation is AC-13, the permeability coefficients corresponding to the three types of deicing salts show an increasing trend with the increase of dry-wet cycle times. Among them, CH_4N_2O has the greatest impact on the permeability coefficient, with an increase of 32.7% and reaching 107.48 mL/min at the 30th cycle; the impact of NaCl on the permeability coefficient is secondary, with an increase of 19.6% and reaching 96.89 mL/min at the 30th cycle, while the impact of CH_2CH_3OH on the permeability coefficient is the smallest, with an increase of 9.0% and reaching 88.32 mL/min at the 30th cycle.

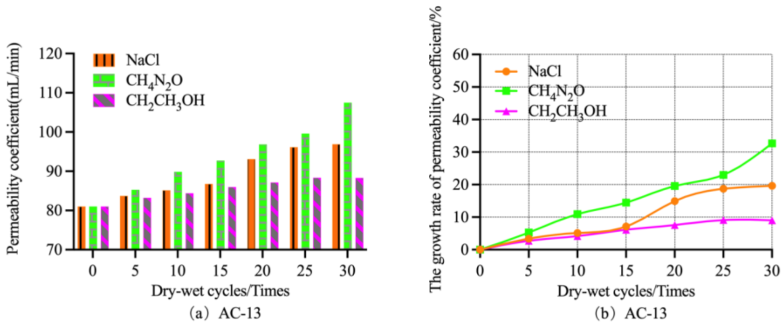

Fig. 3 Variation of permeability coefficient and its growth rate of AC-13 with the increase of dry-wet cycles

When the gradation is AC-16, the changes in permeability coefficient and its growth rate after dry-wet cycle test under three different deicing salt solutions are shown in Figure 4.

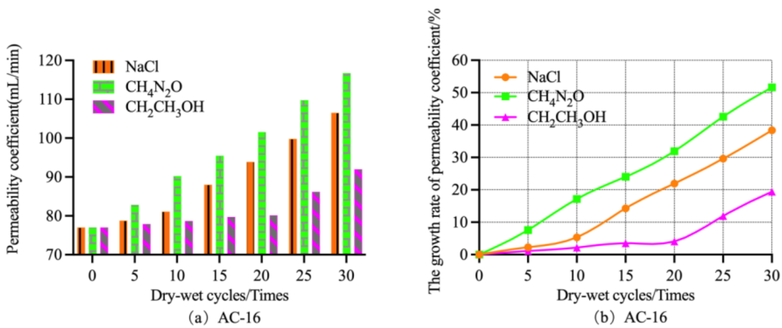

Fig. 4 Variation of permeability coefficient and its growth rate of AC-16 with the increase of dry-wet cycles

From Figure 4, it can be observed that when the gradation is AC-16, the permeability coefficients of the asphalt mixture under the three different deicing salt solutions all show an increasing trend with the increase of dry-wet cycles. Among them, CH_4N_2O has the greatest impact on the permeability coefficient, and its corresponding permeability coefficient increased by 51.6% to 116.75 mL/min after 30 cycles; NaCl has the second largest impact on the permeability coefficient, and its corresponding permeability coefficient increased by 38.4% to 106.54 mL/min after 30 cycles; CH_2CH_3OH has the smallest impact on the permeability coefficient, and its corresponding permeability coefficient increased by 19.4% to 91.96 mL/min after 30 cycles.

By comparing Figure 5 and Figure 6, it can be seen that the growth rate of permeability coefficient for AC-16 is significantly higher than that for AC-13. This indicates that in terms of permeability coefficient, the impact of the three deicing salt solutions on AC-16 is greater than that on AC-13.

Analysis of variance. Analysis of Variance (ANOVA) was conducted to examine the variations in the effects of different factors on air voids, as shown in Table 5.

From Table 5, it can be observed that the significance difference coefficients (Sig.) between different influencing factors and the air voids of asphalt mixtures are all 0, indicating that the number of dry-wet cycles, gradation, and different deicing salt solutions have a significant impact on the air voids of asphalt mixture. From the F-value of the statistics, it can be known that the gradation has the most significant impact on the air voids, followed by the number of dry-wet cycles, and the different deicing salt solutions have the least significant impact.

Table 5

Variance analysis of different influencing factors and air voids

Source	DF	Type III Sum of Squares	Mean Square	F	Sig.
Corrected Model	9	1932.035a	214.671	29.651	.000
Intercept	1	241653.090	241653.090	33378.334	.000
Number of dry-wet cycle	6	1472.055	245.342	33.888	.000
Gradation	1	272.316	272.316	37.614	.000
Solution of deicing salt	2	187.664	93.832	12.961	.000
Error	32	231.674	7.240		
Total	42	243816.799			
Corrected Total	41	2163.709			

Analysis of Variance (ANOVA) was conducted to examine the variations in the effects of different factors on permeability coefficient, as shown in Table 6.

Based on Table 6, it can be observed that the significance difference coefficients (Sig.) between different influencing factors and the permeability coefficient of asphalt mixtures are all 0, indicating that the number of wet-dry cycles, gradation, and different deicing salt solutions have a significant impact on the permeability coefficient of asphalt mixtures. From the F-value of the statistics, it can be seen that the impact of gradation on the permeability coefficient is the most significant, followed by the number of wet-dry cycles, and the different deicing salt solutions have the least significant impact.

Table 6

Variance analysis of different influencing factors and permeability coefficient

Source	DF	Type III Sum of Squares	Mean Square	F	Sig.
Corrected Model	9	13729004.604a	1525444.956	51.670	.000
Intercept	1	372978439.002	372978439.002	12633.498	.000
Number of dry-wet cycle	6	10035856.346	1672642.724	56.656	.000
Gradation	1	1738836.308	1738836.308	58.898	.000
Solution of deicing salt	2	1954311.950	977155.975	33.098	.000
Error	32	944735.177	29522.974		
Total	42	387652178.782			
Corrected Total	41	14673739.781			

Conclusions. After conducting dry-wet cycle tests on AC-13 and AC-16 asphalt mixtures with three types of deicing salts, the following conclusions can be drawn from the analysis of the data on air voids and permeability coefficient:

(1) The impact of deicing salts on air voids and permeability coefficient of asphalt mixtures follows the order: CH_4N_2O > NaCl > CH_2CH_3OH.

(2) The erosion resistance of AC-13 is higher than that of AC-16, indicating that the increase of fine aggregate is beneficial to improving the service life of pavement under salt solution environment.

(3) The growth curves of air voids and permeability coefficient show high correlation, and the increase of permeability coefficient lags behind that of air voids.

(4) The results of the analysis of variance indicate that gradation is the primary factor affecting air voids and permeability coefficient, followed by dry-wet cycle times, and the effect of deicing salt solution is the least significant.

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