https://www.sworldjournal.com/index.php/swj/article/view/swj22-02-007
DOI: 10.30888/2663-5712.2023-22-02-007

UDC 625.855.3

EFFECT OF DEICING SALT ON PERMEABILITY COEFFICIENT OF ASPHALT MIXTURE UNDER FREEZE-THAW CYCLE

Kovalskiy V.P.
c.t.s., as.prof.
ORCID: 0000-0002-3103-6319
Mingjun G.
Ph.D. Candidate
ORCID: 0000-0001-5924-0779
Vinnitsa National Technical University,
Vinnytsia, Voiniv-Internatsionalistiv St, 7, 21000

Abstract. *The widespread use of deicing salt in road maintenance work not only protects the pavements, but also causes serious damage to it. This paper investigates and analyzes the influence of three different deicing salt solutions under three low-temperature environments on the permeability coefficient of two asphalt mixture through freeze-thaw cycles, and based on the experimental results, the significance of each influencing factor on the permeability coefficient of asphalt mixture is analyzed from a statistical perspective. The results show that the permeability coefficients of both dense-graded asphalt mixtures increase to varying degrees after multiple freeze-thaw cycles; when the freezing temperature is higher than the freezing point of the deicing salt solution, the corresponding increase in the permeability coefficient is slow, and the main influencing factor is the erosion damage caused by the salt solution entering the mixture; when the freezing temperature is lower than the freezing point of the deicing salt solution, the corresponding increase in the permeability coefficient is rapid, and the main influencing factor is the severe frozen heaving failure inside the mixture affecting the permeability coefficient, furthermore, variance analysis shows that the freeze-thaw cycle times have the most significant impact on the permeability coefficient.*

Key words: *asphalt mixture, freeze-thaw cycle, permeability coefficient, deicing salt.*

Introduction.

Due to the worsening of climate change, winter snow and ice are causing increasing damage to roads, leading to more frequent road maintenance projects[1]. Deicing salt is currently one of the most common solutions used[2]. However, excessive or improper use of deicing salt can lead to potential problems, particularly in the permeability of asphalt mixtures[3], [4].

During winter, the periodic freezing and thawing cycles experienced by road surfaces have a significant impact on the performance of asphalt mixtures[5]. During freezing, water molecules expand and cause damage to the structure of the asphalt mixture, which can result in a reduction in its performance[6]. During thawing, the water molecules shrink, which leads to an increase in the porosity of the mixture and affects its permeability. Siyu Chen[7] used the Lattice Boltzmann Method (LBM) to predict the three-dimensional permeability coefficient of asphalt mixtures, and found that parameters such as void content, average void diameter, curvature, and anisotropy are highly correlated with the permeability coefficient. Meor Othman Hamzah[8] suggested that under high temperature and over time, the binder will experience creep, which destroys the continuity of the voids, leading to a reduction in the permeability of the mixture. Eyad Masad[9] used numerical simulations to investigate the microstructure of asphalt concrete and found that there are more open flow paths in the horizontal direction than in the vertical direction, resulting in a much higher permeability in the horizontal direction. However, these studies have rarely considered the changes in permeability under salt solution conditions.

Therefore, based on the characteristic climatic environment of Northwest China[10], including the collected data on rainfall, air humidity and pavement interlayer temperature, this paper aims to investigate the effect of deicing salt on the permeability of asphalt mixtures by experimentally studying the variation pattern of the permeability coefficient, and to provide some reference for road design and maintenance.

Experimental materials and methods

The experiment selected KL-90 petroleum asphalt produced by Karamay Refinery in Xinjiang, and its technical indicators were determined through standard procedures, all of which met the specification requirements, as shown in Table 1. The coarse aggregate, fine aggregate, and mineral powder used were all from the Wangjiaping Material Field in Lanzhou City, Gansu Province, and their technical indicators met the specification requirements, as shown in Tables 2 to 4. Urea produced by Liuhua Co., Ltd., industrial salt produced by Baojin Chemical Trading Co., Ltd., and anhydrous ethanol produced by Beichen Fangzheng Reagent Factory were used as three types of deicing salt.

Table 1 - Technical indexes of asphalt

Index	*Test Result*	*Requirement*
Penetration (25 °C, 100 g.5s)/0.1 mm	88.3	80~100
Penetration Index	-1.0	-1.5~+1.0
Extensibility (15 °C)/cm	145	≥100
Softening Point/°C	49	≥45
Flash Point/°C	301	≥245
Density (15 °C)/(g·cm^{-3})	1.033	—
Dynamic viscosity (60°C)/Pa•s	152	≥140
Solubility/%	99.8	≥99.5

Table 2 - Technical indicators of coarse aggregate

Index	*Test Result*	*Requirement*
Crushed Stone Value/%	17.9	≤28
Los Angeles Abrasion Loss/%	17.2	≤30
Solmdness/%	10.8	≤12
Apparent Particle Density	2.82	≥2.5
Water Absorption/%	1.5	≤3

Table 3 - Technical indicators of fine aggregate

Index	*Test Result*	*Requirement*
Apparent Particle Density	2.72	≥2.50
Solmdness/%	9.1	≤12
Sand Equivalent/%	77	≥60
Mud Content/%	2.0	≤3

Table 4 - Technical indicators of mineral powder

Index	*Test Result*	*Requirement*
Density/($t \cdot m^{-3}$)	2.82	≥2.5
Water Absorption/%	0.88	≤1
Hydrophilic Coefficient/%	≤1	≤1
Appearance	No agglomerates	No agglomerates

After considering both the deicing effectiveness and economic feasibility, three deicing salt solutions were prepared for the freeze-thaw cycle solution, including 20% industrial salt (NaCl), 15% urea (CH_4N_2O), and 20% anhydrous ethanol (CH_2CH_3OH). AC-13 and AC-16 gradation rut samples were prepared in advance and cured, and then subjected to freeze-thaw cycle tests for 0, 5, 10, 15, 20, 25, and 30 cycles at three temperatures of -5°C, -15°C, and -25°C, respectively. Each cycle involved immersing the samples in the three solutions for 12±0.5 hours, followed by placing them in a temperature-controlled box for 12±0.5 hours. After the freeze-thaw cycles, the permeability coefficient of the rut samples was measured in accordance with the "Standard Test Methods for Bitumen and Bituminous Mixtures for Highway Engineering" (JTG E20-2011).

Results analysis and discussion

The results of permeability coefficient and its growth rate of asphalt mixture with gradation of AC-13 after freeze-thaw cycles in three different low-temperature environments with three different deicing salt solutions are shown in Figure 1.

From Figure 1(a) and 1(b), it can be observed that when the gradation of the sample is AC-13 and the freezing temperature is -5°C, the permeability coefficients corresponding to the three deicing salts all increase with the increase of freeze-thaw cycles, and the temperature is not lower than the freezing point of the three deicing salts solutions at this time, so the growth rates are all slow. Among them, urea has the greatest influence on the permeability coefficient, and its corresponding permeability coefficient increased by 42.4% to 115.3 mL/min at the end of the cycle; salt has the second largest influence on the permeability coefficient, and its corresponding permeability coefficient increased by 28.3% to 104.0 mL/min at the end of the cycle; alcohol has the smallest influence on the permeability coefficient, and its corresponding permeability coefficient increased by 17.9% to 95.5 mL/min at the end of the cycle.

From Figure 1(c) and 1(d), it can be observed that when the gradation of the sample is AC-13 and the freezing temperature is -15°C, the permeability coefficients corresponding to the three deicing salts all increase with the increase of freeze-thaw cycles, and the permeability coefficient corresponding to urea begins to increase rapidly from the 15th cycle, with a growth rate far higher than those of salt and alcohol, and the freezing temperature has already been lower than the freezing point of urea solution, showing condensation phenomenon. At the end of the cycle, the corresponding permeability coefficient of urea increased by 71.2% to 138.7 mL/min; salt has the second largest influence on the permeability coefficient, and its corresponding permeability coefficient increased by 34.3% to 108.8 mL/min at the end of the cycle; alcohol has the smallest influence on the permeability coefficient, and its corresponding permeability coefficient increased by 26.6% to 102.6 mL/min at the end of the cycle.

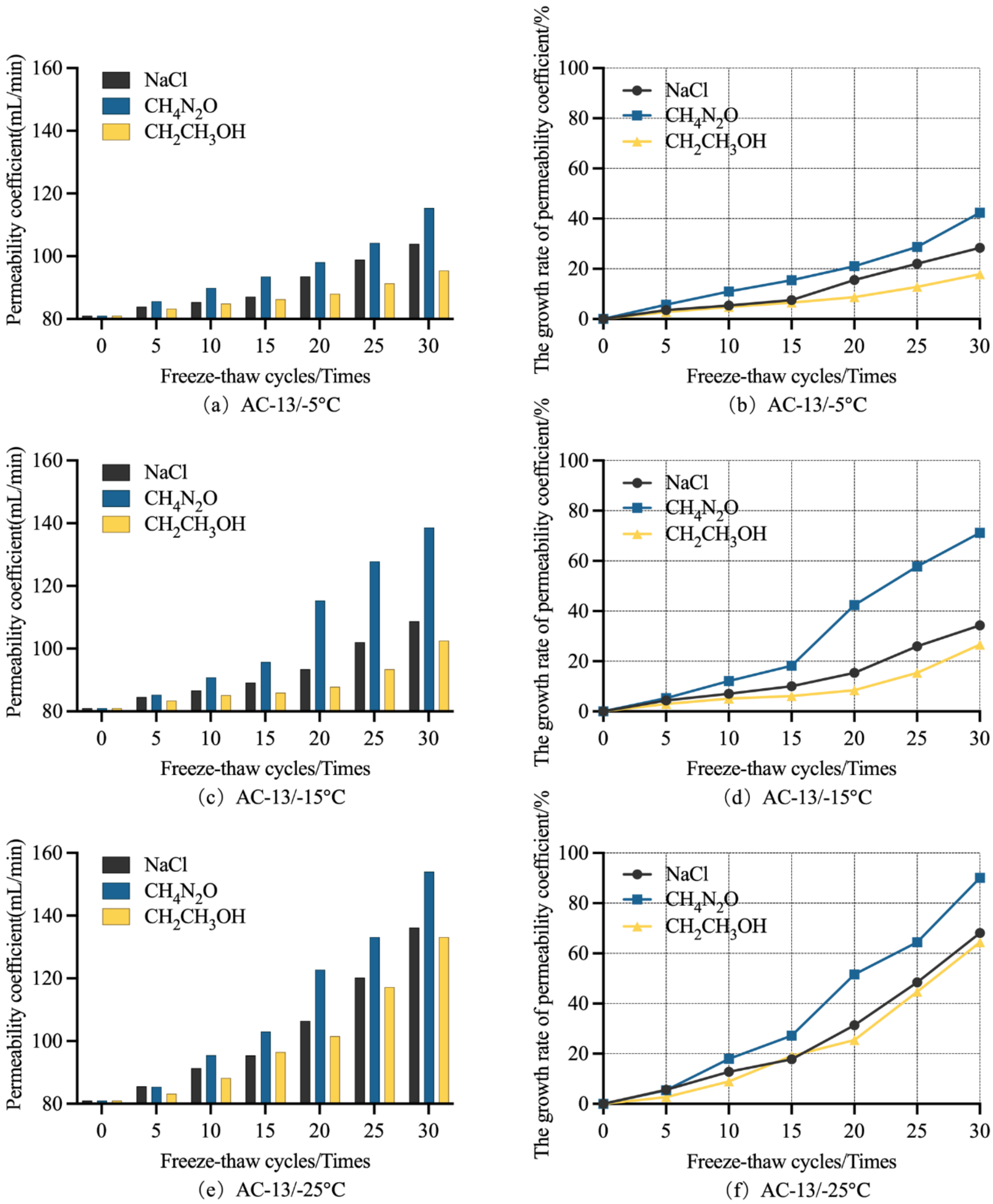

Figure 1 - Variation of permeability coefficient with increasing number of freeze-thaw cycles

From Figure 1(e) and 1(f), it can be observed that when the gradation of the sample is AC-13 and the freezing temperature is -25°C, the permeability coefficients corresponding to the three deicing salts all increase with the increase of freeze-thaw cycles, and the permeability coefficients corresponding to the three deicing salts all begin to increase rapidly from the 15th cycle, and the freezing temperature is lower than the freezing point of the three deicing salts solutions, and all show condensation phenomenon. Among them, urea has the greatest influence on the permeability coefficient, and its corresponding permeability coefficient increased by 90.1% to 154.0 mL/min at the end of the cycle; salt has the second largest influence on the permeability coefficient, and its corresponding permeability coefficient increased by 68.1% to 136.2 mL/min at the end of the cycle; alcohol has the smallest influence on the permeability coefficient, and its corresponding permeability coefficient increased by 64.4% to 133.2 mL/min at the end of the cycle.

The results of permeability coefficient and its growth rate of asphalt mixture with gradation of AC-16 after freeze-thaw cycles in three different low-temperature environments with three different deicing salt solutions are shown in Figure 2.

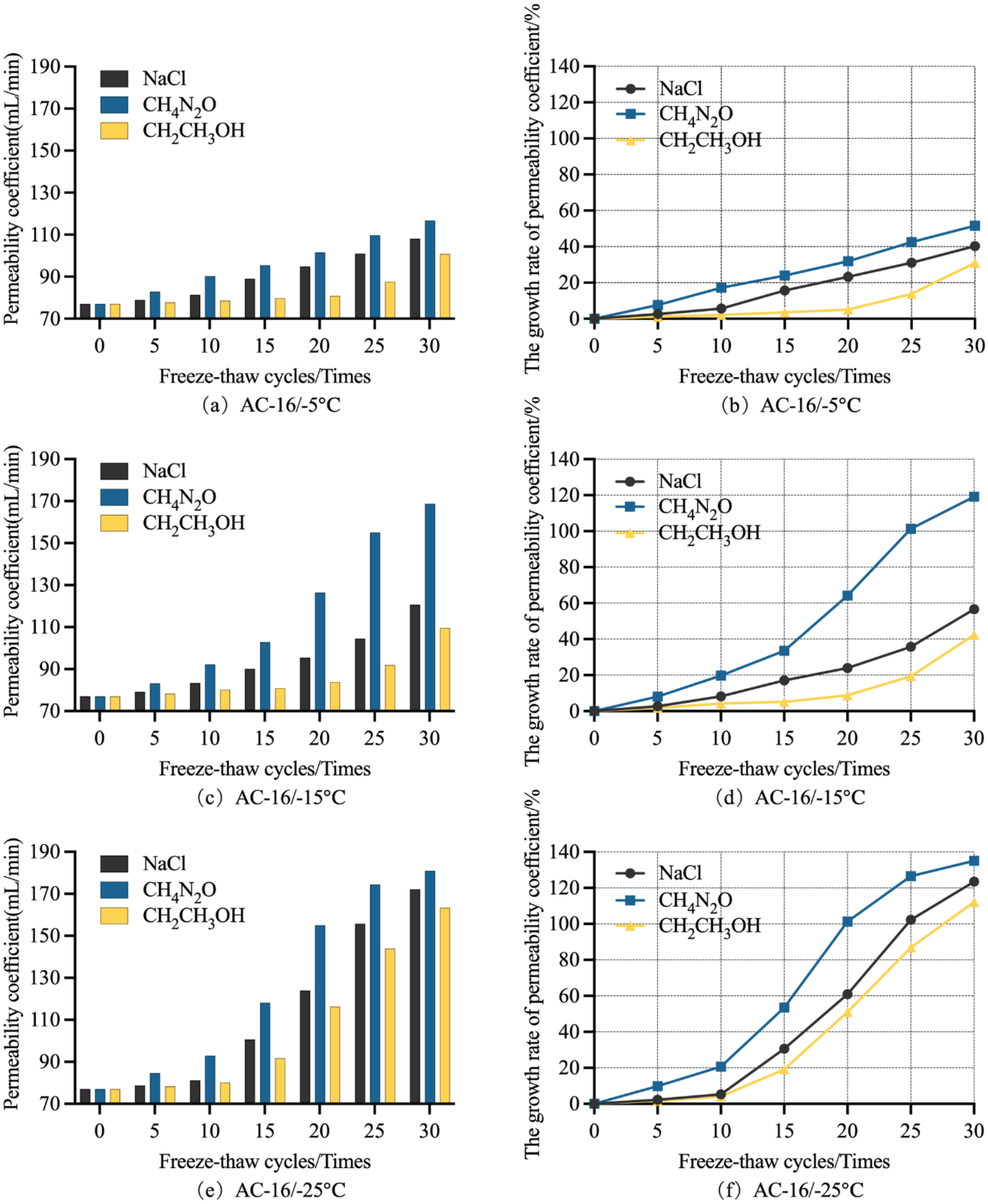

Figure 2 - Variation of permeability coefficient with increasing number of freeze-thaw cycles

From Figures 2(a) and 2(b), it can be seen that when the gradation of the sample is AC-16 and the freezing temperature is -5°C, the permeability coefficients corresponding to the three deicing salts all increase with the increase of freeze-thaw cycles, and the temperature is not lower than the freezing point of the three deicing salts solutions at this time, so the growth rates are all slow. Among them, urea has the greatest impact on permeability coefficient, with an increase of 51.6% to 116.7 mL/min at the end of the cycles; salt has the second largest impact on permeability coefficient, with an increase of 40.28% to 108.0 mL/min at the end of the cycles; alcohol has the smallest impact, with an increase of 30.9% to 100.8 mL/min at the end of the cycles.

From Figures 2(c) and 2(d), it can be seen that when the gradation of the sample is AC-16 and the freezing temperature is -15°C, the permeability coefficients corresponding to the three deicing salts all increase with the increase of freeze-thaw cycles, and the permeability coefficient corresponding to urea begins to increase rapidly from the 15th cycle, with a growth rate far higher than that of salt and alcohol, and the freezing temperature has already dropped below the freezing point of urea solution, leading to condensation. At the end of the cycles, the permeability coefficient corresponding to urea increases by 119.1% to 168.7 mL/min; salt has the second largest impact on permeability coefficient, with an increase of 56.6% to 120.6 mL/min at the end of the cycles; alcohol has the smallest impact, with an increase of 42.4% to 109.6 mL/min at the end of the cycles.

From Figures 2(e) and 2(f), it can be seen that when the gradation of the sample is AC-16 and the freezing temperature is -25°C, the permeability coefficients corresponding to the three deicing salts all increase with the increase of freeze-thaw cycles, and the permeability coefficients for all three types of deicing salts begin to increase rapidly from the 15th cycle, and the temperature has dropped below the freezing point of all three types of deicing salts, leading to condensation. Among them, urea has the greatest impact on permeability coefficient, with an increase of 135.0% to 181.0 mL/min at the end of the cycles; salt has the second largest impact on permeability coefficient, with an increase of 123.5% to 172.1 mL/min at the end of the cycles; alcohol has the smallest impact, with an increase of 112.2% to 163.4 mL/min at the end of the cycles.

Analysis of variance

The variance analysis of different influencing factors and permeability coefficient is shown in Table 5.

From Table 5, it can be seen that the significance difference coefficients (Sig.) between the different influencing factors and the permeability coefficient of the asphalt mixture are all 0, indicating that the number of freeze-thaw cycles, gradation, and different deicing salt solutions have a significant impact on the permeability coefficient of the asphalt mixture. According to the statistical value of F, it is known that the influence of freeze-thaw cycles on the permeability coefficient is the most significant, followed by the gradation of the asphalt mixture, while different deicing salt solutions have the least significant impact.

Table 5 - Analysis of variance between different influencing factors and permeability coefficient

Source	DF	Type III Sum of Squares	Mean Square	F	Sig.
Corrected Model	11	8735.381a	794.126	82.470	.000
Intercept	1	552201.019	552201.019	57346.430	.000
Number of freeze-thaw cycle	6	6056.079	1009.347	104.821	.000
Gradation	1	876.648	876.648	91.040	.000
Solution of deicing salt	2	1351.121	675.560	70.157	.000
Error	2	451.533	225.767	23.446	.000
Total	114	1097.730			
Corrected Total	126	562034.130			

Conclusions

By conducting freeze-thaw tests on two types of dense graded asphalt mixtures under three different deicing salt solutions and three different low-temperature environments, the following conclusions can be drawn by analyzing the variation pattern of the permeability coefficient:

(1) Under the three low-temperature conditions, the order of the impact of deicing salt on the permeability coefficient of asphalt mixture from large to small is: urea > industrial salt > ethanol.

(2) When the freezing temperature is higher than the freezing point of the deicing salt solution, the corresponding permeability coefficient increases slowly but still increases slightly, at this time, the main influencing factor is the erosion damage caused by the salt solution entering the mixture; when the freezing temperature is lower than the freezing point of the deicing salt solution, the corresponding permeability coefficient will show a rapid increase, at this time, the main influencing factor is the serious damage caused by freezing and expansion inside the mixture, which severely affects the permeability coefficient.

(3) Through variance analysis, it is known that the influence of freeze-thaw cycles on the permeability coefficient is the most significant, followed by the gradation of the asphalt mixture, while the impact of different deicing salt solutions is the least significant.

References:

[1] V. P. Kovalskiy and G. Mingjun, "The influence of deicing salt on air voids of asphalt mixture under freeze-thaw cycle," Сучасні Технології Матеріали І Конструкції В Будівництві№ 1 43–50, 2023.

[2] H.-C. Dan, J.-W. Tan, Y.-F. Du, and J.-M. Cai, "Simulation and optimization of road deicing salt usage based on Water-Ice-Salt Model," Cold Reg. Sci. Technol., vol. 169, p. 102917, Jan. 2020, doi: 10.1016/j.coldregions.2019.102917.

[3] C. D. Johnston, "Deicer Salt Scaling Resistance, Chloride Permeability and Code Requirements for Air Content, Spacing Factor," Concr. Int., vol. 16, no. 8, pp. 48–55, 1994.

[4] S. P. Kakuturu and S. E. Clark, "Clogging mechanism of stormwater filter

media by NaCl as a deicing salt," Environ. Eng. Sci., vol. 32, no. 2, pp. 141–152, 2015.

[5] M. Guo, V. P. Kovalskiy, T. Nian, and P. Li, "Influence of Deicer on Water Stability of Asphalt Mixture under Freeze–Thaw Cycle," Sustainability, vol. 15, no. 18, p. 13707, 2023.

[6] C. Zheng, J. Xu, T. Zhang, and G. Tan, "Study on the microscopic damage of porous asphalt mixture under the combined action of hydrodynamic pressure and ice crystal frost heave," Constr. Build. Mater., vol. 303, p. 124489, Oct. 2021, doi: 10.1016/j.conbuildmat.2021.124489.

[7] S. Chen, Z. You, S.-L. Yang, A. Garcia, and L. Rose, "Influence of air void structures on the coefficient of permeability of asphalt mixtures," Powder Technol., vol. 377, pp. 1–9, Jan. 2021, doi: 10.1016/j.powtec.2020.08.082.

[8] M. O. Hamzah, M. R. M. Hasan, and M. van de Ven, "Permeability loss in porous asphalt due to binder creep," Constr. Build. Mater., vol. 30, pp. 10–15, 2012.

[9] E. Masad, A. Al Omari, and H.-C. Chen, "Computations of permeability tensor coefficients and anisotropy of asphalt concrete based on microstructure simulation of fluid flow," Comput. Mater. Sci., vol. 40, no. 4, pp. 449–459, 2007.

[10] Yang liu and Ping Li, "Study on Temperature Field Prediction Model and Anti Icing Technology of Asphalt Pavement in Winter of Gansu Province," Master, Lanzhou University of Technology, 2018.

Article sent: 8.11.2023 p.