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Laboratory evaluation of long-term anti-icing performance and moisture susceptibility of chloride-based asphalt mixture

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Abstract

The objective of this research is to investigate the long-term anti-icing performance and moisture susceptibility of chloride-based asphalt mixture. Two experiments (the natural and accelerated dissolving-out methods) were conducted on the Marshall samples and their salt releasing amount were determined based on the density measurement of the aqueous solution with a hydrometer. In addition, the impact of anti-icing agents (MFL) on the mixture water stability was also investigated. Results show that a similar tendency in both methods was observed and the salt dissolution history was generally divided into three phases. Most notably, compared with the natural dissolving-out experiment the accelerated test was more effective and time-saving. Moreover, asphalt concrete with MFL performed poorer water damage resistance than the conventional asphalt concrete and the residual stability of the former declined more dramatically than the later. Finally, based on the 60 °C dissolving-out experiment, a model to predict the effective working time of the anti-icing asphalt pavement was proposed subsequently.

Keywords: Asphalt mixture; Chloride; Long-term anti-icing performance; Moisture susceptibility

1. Introduction

Statistics show that approximately more than 30% of winter traffic accidents are associated with snow and ice on pavement surface [1,2]. The black ice on the pavement not only poses a great threat to the smooth and secure flow of traffic but also leads to high maintenance budgets [3]. Therefore, deicing and anti-icing technology has long been an central issue for pavement practitioners [4,5]. Anti-freezing asphalt pavement is a new pavement by adding certain anti-icing chemicals (usually chlorine salt) into asphalt mixture [6]. Originally applied in Europe in the 1960s, this pavement has been widely used in Switzerland, Japan, Germany and China [7–9]. The chemicals are crucial to melt snow and ice and primarily adopted chemical fillers are sodium chloride, calcium chloride and magnesium chloride [10]. When subjected to traffic loads these ingredients inside the pavement dissolve out

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gradually under capillary attraction and then deposit on the pavement surface, lowering the freezing point of melt water and restraining ice and snow from accumulation [10]. Many efforts have been made to promote the progress of this pavement. For example, in the 1990s researchers in Japan developed a new porous anti-icing filler known as MFL that was widely applied across the world [11,12]. Wang analyzed the influence of salt content, temperature and void ratio on the dissolving-out law by determining the conductivity of salt solution [13]. Liu et al. focused on the properties of asphalt mixtures containing anti-freeze fillers with the volume replacement method and investigated the void content, high and low temperature properties and the susceptibility to moisture damage by experimental method [14]. Zhang et al. adopted indoor simulating tester for anti-freeze pavement to verify the anti-freeze capability of MFL modified asphalt concrete and its snow melting function by observing the testing process [15]. On the whole, current investigations on the anti-icing asphalt mixtures primarily focused on the short-term snow melting performance by naked eye observation, and on the influence of anti-icing fillers on mixture performance. Little work has been reported about the long-term performance of chloride-based asphalt mixtures since there is no consistent method to evaluate the mixture long-term anti-icing property [16]. Moreover, when exploring the salt dissolving-out progression in the anti-icing mixtures, the conductivity test is widely used. However, it will be beyond range when the salt dissolving-out amount reaches a certain high value. Nevertheless, little work has been reported currently to overcome the limitation of this method.

In this view, this study aimed to evaluate the long-term anti-icing performance of the chloride-based asphalt mixture and to investigate the impact of chloride chemical on the mixture moisture susceptibility. In this study, the Marshall samples of asphalt concrete added with MFL powder were prepared and two experimental programs (natural dissolving-out experiment and accelerated dissolving-out experiment) were conducted. To avoid the aforementioned limitations of the conductivity test, the release amount of anti-icing salt was determined by measuring the solution density using a hydrometer in this research. In addition, the residual Marshall stability of asphalt concrete with or without MFL were compared and analyzed. Finally, a logarithm between the dissolving-out percentage and time was fitted and a model to predict the effective working time of the anti-icing pavement was then presented.

2. Materials and experiments

According to the current literature, there is no standard test method to evaluate the anti-icing performance of the snow melting asphalt mixture in the long run [16]. In this study two experiments were designed to assess the long-term anti-icing property based on the dissolving out amount of salts in the mixture. This section presents the basic materials and test methods included in this study.

2.1. Raw materials

2.1.1. Binder and aggregate

A Styrene Butadiene Styrene (SBS) modified asphalt binder from Wuhan was used in this experiment and its main technical properties are listed in Table 1.

The crushed basalt, long been regarded as the best choice for hot asphalt mixture in current China [17], was used as the coarse aggregate and the machine-made sand from the basalt stone was applied as the fine aggregate. In addition, the mineral filler included in this research was from the Jingshan stone plant. The physical and mechanical properties of the coarse and fine aggregates are shown in Tables 2 and 3. Based on the AC-13 gradation, three preliminary gradations were designed and then tested to select an optimal one leading to a mixture of appropriate void volume (VV), good high temperature stability and enough surface texture depth. The selected gradation is shown in Table 4.

2.1.2. Anti-icing additive

According to common practice, two types of anti-icing chemicals are predominantly used in the anti-icing asphalt pavement, which are the granular filler and the anti-icing powder. Generally their anti-freezing capabilities differ

Table 1
Properties of the binder.

Indicator	Test value	Requirement	Test method [18]
Penetration (0.1 mm)	58	40–60	T0604
Penetration index	0.126	⩾0	T0604
Softening point (°C)	84	⩾75	T0606
Ductility (cm)	22.7	⩾20	T0605
Viscosity (Pa s)	1.14	⩽3	T0625
Flash point (°C)	273	⩾230	T0611
Solubility (%)	99.4	⩾99	T0607
Elastic recovery (%)	89	⩾75	T0662
Softening point difference after 48h thermal storage (°C)	1.9	⩽2.5	T0661
Density (g/cm^3)	1.022	Test value	T0603
TFOT mass change (%)	0.06	⩽1.0	T0609
Penetration ratio (%)	75.9	⩾65	T0604

Table 2
Properties of the coarse aggregate.

Indicator		Test value	Requirement	Test method [19]
Crushed stone value (%)		11.6	⩽26	T0316
Abrasion value (%)		10.8	⩽28	T0317
Mud content (%)		0.6	⩽3	T0314
Adhesion		level 5	above level 4	T0616
Apparent density (t/m^3)	9.5–16 mm	3.048	⩾2.6	T0304
	4.75–9.5 mm	2.993		
Bulk density (t/m^3)	9.5–16 mm	2.996	–	T0304
	4.75–9.5 mm	2.904		
Flat and elongated particle content (%)	>9.5 mm	5.2	⩽15.0	T0312
	<9.5 mm	7.8	⩽20.0	
Water absorption (%)	9.5–19 mm	0.45	⩽2.0	T0304
	4.75–9.5 mm	0.63		

Table 3
Properties of the fine aggregate.

Indicator		Test value	Requirement	Test method [19]
Apparent density (t/m^3)	2.36 ~ 4.75 mm	2.872	⩾2.5	T0328
	0 ~ 2.36 mm	2.895		
Bulk density (t/m^3)	2.36 ~ 4.75 mm	2.843	–	T0304
	0 ~ 2.36 mm	2.895		
Sand equivalent		98	⩾60	T0334
Mud content (%)		1.3	⩽3.0	T0333

Table 4
Aggregate gradation in the test.

Sieve size (mm)	16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Passing percentage (%)	100	97.7	75.0	49.2	36.7	26.7	17.6	14.2	10.6	5.6

Table 5
Properties of the MFL powder.

Index	Test result
Density (t/m^3)	2.295
Salt content (%)	56.0
pH	8.2
Moisture content (%)	0.2

greatly from each other because of their different physical properties and chemical ingredients. In this study, a Japanese MFL powder was added to the dense graded asphalt mixture, which is mainly composed of chlorine salts such as sodium chloride, calcium chloride, magnesium chloride as well as silicon dioxide. Moreover, among these ingredients the most effective part is the sodium chloride which accounts for over 55% of the mass fraction. The major technical property and the grain composition of the MFL powder are shown in Tables 5 and 6.

2.2. Mixture

In this paper, the anti-icing asphalt mixture was designed primarily based on the Marshall Mixture design procedure (AASHTO 1997) [18]. But some amendments were applied to this method in that adding anti-icing fillers changes the original aggregate gradation. On the other hand, special attention was paid to the selection of an appropriate air void volume. Since the anti-freezing particles are relatively large once they separate out from the mixture, a considerable reduction in the water stability, thermal cracking resistance as well as the high temperature stability of the mixture was found. In this view, smaller void volume was preferable. Nevertheless, asphalt mixtures with too small void volume is highly susceptible to bleeding since there is no adequate air void to accommodate the hot melting asphalt binder [20–22]. The minimum void volume is usually no less than 3% in terms of bleeding and post-compression theory [23]. Regarding the fact that the void volume will increase further after the anti-icing particles dissolve out from the mixture, a 3% void volume was adopted as the target value. The optimum asphalt content was determined as 4.8% by weight of mineral aggregate according to the test results.

As previously mentioned, some amendments were adopted to revise the Marshall method since the MFL powder was used to replace the mineral filler. Generally, the MFL powder has similar gradation to the mineral filler and it can be used to partially or completely replace the mineral fillers. But the density of the former (2.25–2.35 t/m^3) is less than that of the latter (about 2.5 t/m^3). When replacing at equal weight, the filler volume in the mixture increases and the mixture mobility reduces consequently,

Table 6
Particle composition of the MFL powder.

Sieve size (mm)	16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Passing percentage (%)	100	100	100	100	100	100	100	95	91.0	74.3

Table 7
Original and revised gradation of the anti-icing mixture.

Sieve size (mm)	16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075	MFL
	Passing percentage (%)										
Original	100	97.7	75.0	49.2	36.7	26.7	17.6	14.21	10.55	5.62	5
Revised	100	97.7	75.0	49.2	36.7	26.7	17.6	14.22	10.9	6.4	4.6

Table 8
Marshall testing results of the mixtures with or without MFL.

Indicator	AC-13	AC-13 (with MFL)	Requirement [23]
Optimum asphalt content (OAC, %)	4.8	4.8	–
Void volume (VV, %)	2.6	2.9	3
Voids in mineral aggregate (VMA, %)	13.40	13.43	>12.5
Void filled with asphalt (VFA, %)	80.12	78.72	65–75
Marshall stability (MS, kN)	14.23	14.46	⩾8
Flow value (FL, mm)	3.40	3.02	2–4

leading to mixture clumps that is not easy to blend and pave [24]. Therefore the volume-equivalent replacement method was used to revise the MFL content. Based on the gradation described in Table 4, the revised gradation after adding MFL is shown in Table 7.

Combined with the aforementioned optimum asphalt content (4.8% by weight of mineral aggregates) and the MFL content (4.6% by weight of aggregates), the Marshall test was carried out and its results are shown in Table 8. For comparison, the conventional dense graded asphalt concrete AC-13 was also tested and its results are also shown in Table 8.

According to Table 8, after adding MFL into the mixture the void volume changed little and all the indicators could satisfy the requirements in the code. Therefore this research still adopted the original gradation and optimum asphalt content to evaluate the long term performance of asphalt mixture containing MFL fillers.

2.3. Experimental program

It is widely accepted that the anti-icing performance of chloride based asphalt mixture is closely related to the salt content of mixture and the concentration of saline solution formed on pavement surface after putting in use. In this research, the Marshall samples of the anti-icing mixture were prepared and soaked in fresh water and their salt dissolving-out amount at different times was measured which helped to predict the long-term snow melting performance of the mixture. Particularly, two experimental programs were designed to reflect the salt transfer rule under different conditions. One is the natural dissolving-out experiment and the other is the accelerated dissolving-out experiment.

2.3.1. Natural dissolving-out experiment

In the natural dissolving-out experiment, the prepared Marshall samples were immersed into certain amount of fresh water at ambient temperature (25 °C). Afterward, the chlorine salts gradually separated out from inside the mixture and dissolved in the water, leading to an increase in the solution concentration. Based on the measured concentration change, the salt releasing amount was determined and then used to predict the anti-icing performance of the mixture.

Notably, salt dissolving-out amount of the samples in this study was investigated under two conditions: the top-only condition and the bottom-excluding condition. According to the former, sealing materials were applied to the sample surface except for the top and the chlorine salt could only separate out from the sample top. Whereas in the bottom-excluding condition, sealing materials was simply used to the sample bottom to accelerate the salt separation by enhancing effective contact between sample and solution. Although the top-only condition is much closer to actual pavement situation, this study still adopted the bottom-excluding method since the dissolving and precipitating rate under the top-only condition is extremely slow. Testing results are accurate only when the solution concentration is sufficiently high.

The procedure of the natural dissolving-out experiment is as follows.

The prepared sample was firstly sealed up at its bottom and weighed. Then it was placed into a container and the total weight of container and sample was measured. After putting 500 mL distilled water into the container and sealing it up, the initial gross weight of the container, sample and water was measured. Subsequently, the sample was soaked in the water at room temperature and density measurements

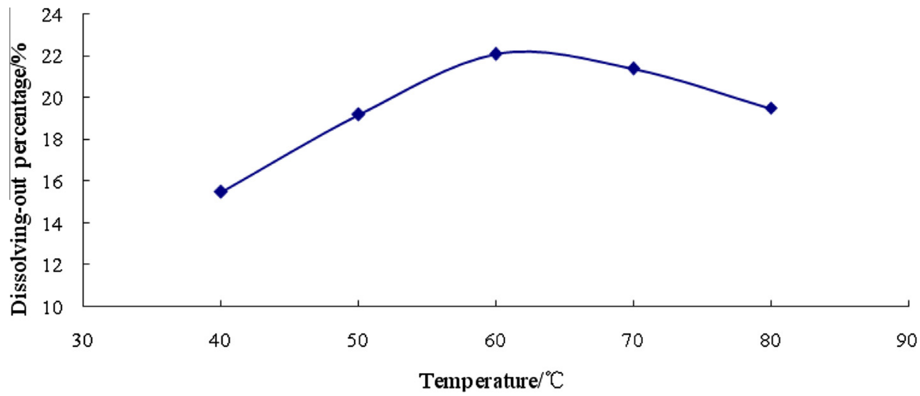

Fig. 1. Dissolving-out percentage at different temperatures.

were carried out every 5 days. If the density change was inconspicuous, testing intervals can be prolonged appropriately. It should be noted that when the total weight of the three measured later was less than the original value, some water was needed to keep it constant. The solution density was measured with a hydrometer and no solution waste was allowed during the measurement. After the density measurement was accomplished, the solution should be poured back into the container to continue the experiment. If solution density changed little after 50 days, the measurement can be implemented every 10 days. Until the salt dissolving-out percentage reached more than 90%, the experiment could be stopped. In order to show the deviation, four parallel samples were included in the experiment and finally the mean value of them was taken as the final result.

Based on the measured density, the solution concentration in the natural dissolving-out experiment could be determined and the salt dissolving-out percentage in the mixture was calculated as follows.

$$m_1 = \frac{M \cdot r}{1 + OAC} \tag{1}$$

$$A = m_1 \cdot c \tag{2}$$

$$P = \frac{(\rho_2 - \rho_1) \cdot m_2}{A \cdot \rho_1} \tag{3}$$

where $\boldsymbol{M}$ is the weight of sample (g); $\boldsymbol{OAC}$ is the optimum bitumen-aggregate ratio (%); $\boldsymbol{r}$ is the weight ratio of MFL to mineral aggregate (%); $\boldsymbol{m_1}$ is the content of MFL in the sample (g); $\boldsymbol{m_2}$ is the weight of distilled water (g); $\boldsymbol{c}$ is the content of anti-icing attributes in MFL (%); $\boldsymbol{\rho_1}$ is the density of water (g/cm^3); $\boldsymbol{\rho_2}$ is the density of the dilute solution (g/cm^3); $\boldsymbol{A}$ is the weight of anti-icing attributes in the sample (g); $\boldsymbol{P}$ is the salt dissolving-out percentage (%).

2.3.2. Accelerated dissolving-out experiment

Although the natural dissolving-out method may be used, it is time-consuming and needs to be revised for a higher efficiency. Hoiberg et al. found that the stiffer the asphalt was the less permeable it became [25] and the permeability coefficient of straight-run asphalt was smaller than that of the oxidized asphalt [26]. With the temperature increasing asphalt got softer and its permeation coefficient increased gradually. For example, the permeability coefficient of the bitumen at 55 °C is about 3 times of that at 15 °C. Moreover according to the molecular diffusion theory salt dissolving-out history can be accelerated by warming up the dilute solution.

However, an appropriate temperature is critical to the accelerated dissolving-out experiment. To determine the optimum temperature the samples were tested at five different temperatures (40 °C, 50 °C, 60 °C, 70 °C and 80 °C) and their 48 h dissolving-out percentage were calculated. The results are shown in Fig. 1.

It can be seen in Fig. 1 that the dissolving-out percentage increased originally as the temperature went up and then peaked at 60 °C. When the test temperature exceeded 60 °C, the salt dissolving-out percentage decreased. The first increase in the dissolution may be resulted from the violent molecular motion and high asphalt water permeability related to higher temperature. However when the temperature went beyond 60 °C, the dissolution began to decrease since the enhanced water permeability of asphalt had little to do with the mixture permeability. On the contrary, the hot binder flew and blocked some pores inside the mixture which may prevent salt inside the mixture from dissolving out further.

As shown in Fig. 1, the temperature corresponding to the peak dissolving-out percentage is around 62 °C, and therefore 60 °C was finally adopted in the accelerated dissolving-out experiment.

2.3.3. Water stability test

The residual Marshall stability test was adopted to evaluate the long-term moisture susceptibility of the anti-icing asphalt mixture. Two mixtures were adopted (one is AC with MFL and the other control piece is asphalt concrete without MFL) and the test was carried out every other day after the samples were soaked in the aqueous solution.

3. Results and discussion

This section presents the results of the long-term dissolving-out experiments at ambient temperature as well

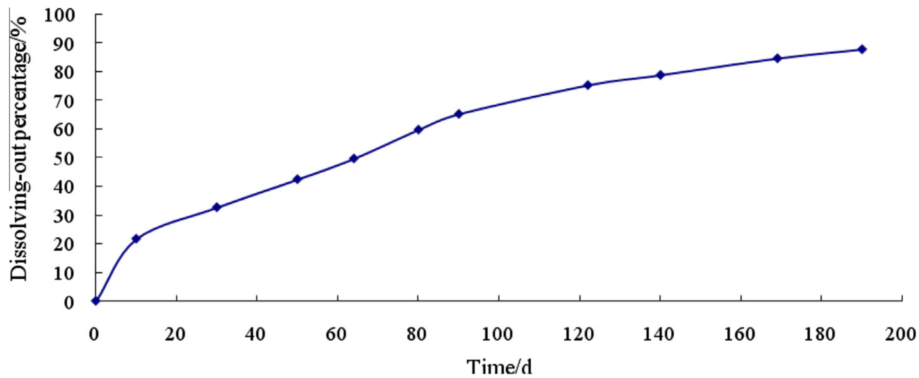

Fig. 2. Salt dissolving-out curve with time in natural dissolving-out test.

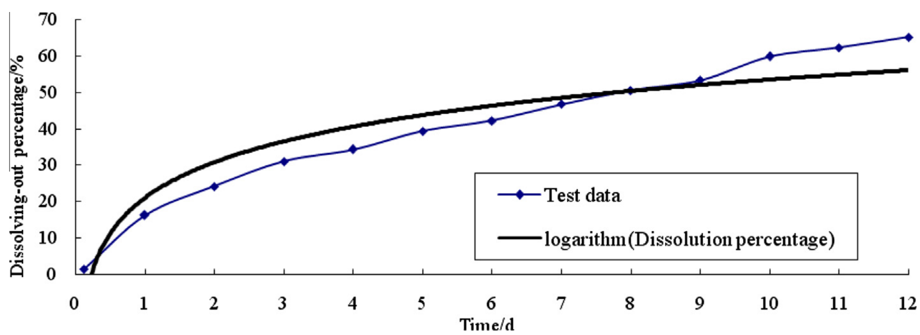

Fig. 3. Dissolving-out percentages at different days.

as that at 60 °C condition. Also, the relationship between the natural dissolving-out result and the accelerated test was analyzed and a logarithm to predict the effective working time of the snow melting asphalt mixture was fitted on the basis of the test data. In addition, the impact of the anti-icing agents on the water stability of the mixture was also discussed herein.

3.1. Results of natural dissolving-out experiment

The results of the natural dissolving-out experiment are shown in Fig. 2.

As seen in Fig. 2, the salt dissolving-out history could be divided into three phases. The first was the rapid dissolving-out period which was from the beginning to the 10th testing day. The second was the steady releasing period with a constant rate and lasting from the 10th day to the 110th day. The last phase was the slowly dissolving-out period after the 110th day, featuring a gradually decreasing dissolving-out rate.

The reason for the rapid salt dissolution initially was that when preparing the sample a small part of salt was left over on the sample surface, they dissolved quickly once meeting the water. In addition the anti-icing attributes inside the sample dissolved simultaneously, leading to a rapid dissolution rate at the first stage.

However at the second stage the salt dissolved out at a constant speed which mainly resulted from two actions that formed a balance. One was the increased release of salt inside the mixture by the capillary attraction and the other was the gradually slowed separation of salt on the surface of the sample.

Finally, the third period showed a decelerated dissolving-out rate and it was primarily due to the completion of the salt separation on the sample surface and inside the piece. Since the anti-icing attributes in this period were far less than that in the previous stages and the effective dissolving out area has been dramatically reduced, therefore the salt dissolving-out process slowed down accordingly.

3.2. Results of accelerated dissolving-out experiment

The accelerated dissolving-out experiment using the Marshall samples was conducted at 60 °C and a logarithm with a satisfactory goodness was fitted on the test data to show the relationship of the dissolving-out percentage with time (shown in Fig. 3). The logarithm could be expressed as follows.

$$u_1 = 14.137 \ln t_1 + 21.097 (t_1 \geqslant 0.25)(R^2 = 0.8947) \quad (4)$$

where $\boldsymbol{u_1}$ is the dissolving-out percentage (%); $\boldsymbol{t_1}$ is the soaking time of samples(d) and it is usually no less than 0.25 to keep $\boldsymbol{u_2}$ greater than 0.

Take the derivative of time, Eq. (4) transforms into Eq. (5) which denotes the tangent of the dissolving-out percentage time curve:

$$u_1' = 14.137/t_1 \quad (5)$$

where u_1' is the rate of dissolving-out percentage.

It can be drawn from Eq. (5) that the salt dissolving-out rate in the accelerated dissolving-out program decreased with time increasing, which is in good agreement with the tendency in the natural dissolving-out experiment.

3.3. Prediction of effective anti-icing time

It is widely accepted that the anti-icing attribute separated out from the asphalt mixture plays an important role in melting ice and snow on road surface during snowy days. The more the anti-icing attributes separate out, the better the snow melting performance is. Therefore, this research adopted the long-term salt dissolving-out percentage to evaluate the snow melting performance of the mixture. As previously mentioned the dissolving-out tendency in the accelerated test was similar to that in the natural dissolving-out experiment. Therefore, a more reasonable dissolving-out law of the salt can be obtained based on both the natural dissolving-out results and the accelerated results.

According to the test data, the accelerated dissolving-out quantity was approximately 8 times of that in the natural dissolving-out experiment. Consequently, a new set of data can be obtained by multiplying the testing time of the accelerated test by 8. Then a new curve was drawn based on the expanded dissolving-out data. Fig. 4 shows the curve and its fitting logarithm. The fitting logarithm of the expanded dissolving-out data can be expressed as follows:

$$u_2 = 23.146 \ln t_2 - 40.955 (t_2 \geqslant 8) \; (R^2 = 0.9320) \quad (6)$$

where u_2 is the expanded dissolving-out percentage(%); t_2 is the soaking days of the sample and it is usually no less than 8 to keep u_2 greater than 0 (d).

As seen in Fig. 4, this logarithm fits the test results well with a considerably high goodness ($R^2 = 0.9320$) and Eq. (6) can be used to evaluate the long term anti-icing performance of the mixture. However, the natural dissolving-out experiment is time-consuming and inefficient for practical use. Whereas the testing time in the accelerated experiment is dramatically cut down, therefore the 12-day 60 °C accelerated experiment was adopted eventually to evaluate the long-term anti-icing performance of the mixture in this study.

According to Eq. (4) , when t_1 equals to $t/8$ this equation transforms to Eq. (7):

$$u = 14.137 \ln t - 8.3001 \, (t \geqslant 2) \quad (7)$$

When the salt dissolving-out percentage equals to u, the effective working time of the anti-icing salt in the pavement can be calculated as follows:

$$t = e^{(u+b)/a}/K \quad (8)$$

where t is the effective working time; a is 14.137; b is 8.3001; K is the area conversion factor and it is 3.5 ($K = S_1/S_2, S_1 = \pi r^2 + 2\pi rh, S_2 = \pi r^2$, r and h is the radius and height of Marshall specimen respectively.)

When the salt is 100% dissolved out from the asphalt mixture to the pavement surface (or rather, u equals to 100), the predicted effective working time of the anti-icing asphalt pavement can be calculated as follows:

$$T = e^{(100+b)/a}/K \quad (9)$$

However, the predictive model shown in Eq. (9) needs to be adjusted for different situations. For example, for other mixture gradations, the accelerated dissolving-out test can be conducted to establish a model like Eq. (7) and to determine the constants (a, b). Then, the effective working time can be determined thereupon. It should be noted that the working time is the continuous working time of the anti-icing asphalt pavement in continued snowy days.

Considering the basic parameters, the effective working time of the anti-icing pavement in this study was 607 days according to the above model, which means that the pavement can work for 607 days when exposed to continuous snowy days. However, for application in other situations, actual snowfall days offered by the meteorological department should be adopted to revise the prediction.

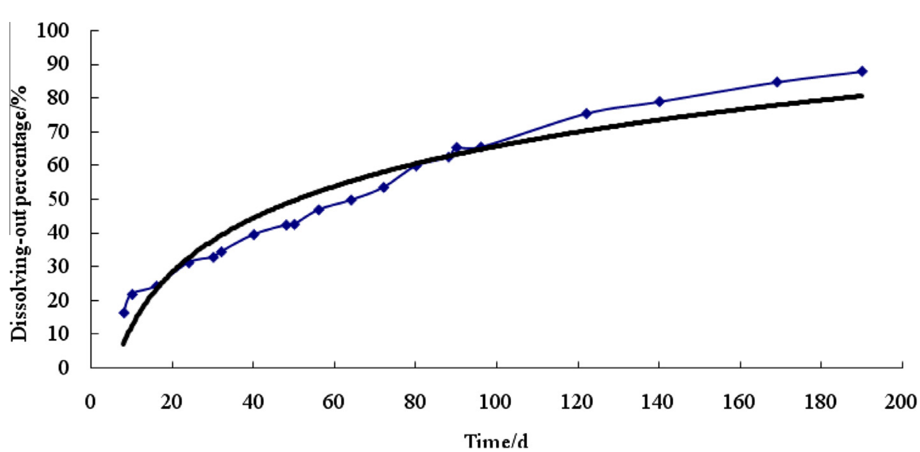

Fig. 4. Expanded dissolving-out percentage at different days and its fitting curve.

Although, factors influencing the in-situ snow melting performance such as snowfall amount, environmental temperature, moisture content, axle loads etc. are more complicated than that in this experiment, this research made an valuable exploration in the cognition of the long-term salt release law in the chloride-based asphalt pavement.

3.4. Effect of MFL on mixture water stability

The results of the residual Marshall stability test of the two mixtures (AC with MFL and the control) are shown in Fig. 5.

As shown in Fig. 5, both the control and the AC with MFL piece showed decrease in the Marshall stability with the soaking time went by. Particularly, the latter decreased more remarkably than the former and it decreased approximately in a linear way. In addition, it was noted the 8th day marked a significant stability difference (greater than 2 kN) between the two samples. Most notably, on the 12th day the residual stability of the AC with MFL piece was below 8 kN which is the minimum value in the code, and hence the experiment had to be stopped.

Fig. 5 also shows that compared with the control sample, a rapid decline in the residual stability of the AC with MFL was found. On the 6th day, the residual stability of the AC with MFL was less than 75% (minimum value in the code). While the control mixture reached the same value much later, almost on the 9th day. Some reasons such as high air void, poor adhesion between the binder and the aggregate as well as weakening of the asphalt mastic may account for the rapid decline in the residual stability of the anti-icing mixture.

It has been commonly accepted that a large number of pavement moisture damages resulted from the weakening of adhesion between binder and aggregates. The adhesion mechanism between them is usually categorized as the chemical absorption and the physical adhesion. The former is mainly related to the chemical reaction between the bitumen and the metallic cations on the aggregate surface, whereas the physical adhesion is mainly dependent upon the intermolecular force. Since the chemical absorption is usually greater than the physical adhesion, it plays a dominant role in the binder-aggregate adhesion and is critical to the mixture moisture susceptibility.

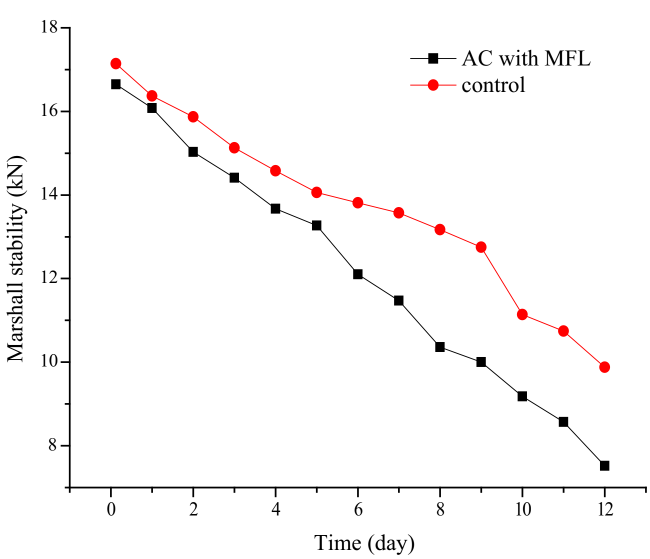

Fig. 5. Marshall stability at different times.

In this study, the AC with MFL showed poor long-term water damage resistance than the control piece and the reasons may lie in two facts. On the one hand, the mixture has a weaker chemical absorption between binder and aggregates which resulted from the replacement of mineral filler by the anti-icing powder. On the other, a greater void volume was attained after the anti-icing salt separated out which increased the risk of moisture damage. In this view, some countermeasures are highly recommended to enhance the moisture resistance of the mixture such as selecting appropriate aggregate and asphalt binder, adopting effective anti-stripping agents etc.

4. Conclusions

This research adopted the 60 °C dissolving-out experiment to evaluate the long-term anti-icing performance of chloride-based asphalt mixture, and a model to predict the effective working time of the anti-icing asphalt pavement was proposed subsequently based on the laboratory test. In addition, the impact of anti-icing agents on the mixture water stability was also investigated. Some preliminary conclusions can be drawn as follows:

(a) The salt dissolution progression both at ambient temperature and at 60 °C could be divided into three phases. Compared with the natural dissolving-out experiment, the accelerated dissolving-out test was more effective and timesaving.
(b) In the accelerated test, the optimal temperature for asphalt mixture added with MFL was around 60 °C.
(c) A model to predict the effective working time of the anti-icing pavement was proposed based on the lab accelerated experiment and local meteorological information should be taken into account to calibrate the prediction.
(d) Asphalt concrete with MFL performed poorer water damage resistance than the conventional asphalt concrete and the residual stability of the former declined more dramatically than the later. Therefore, rigid measures should be taken to improve the water stability of the anti-icing asphalt mixture.

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