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Experiment on Road Performance of Asphalt Mixture with Automatic Long-term Snowmelt Agent

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Abstract: Asphalt mixture with Mafilon (abbreviated as MFL) is an automatic long-term snowmelt asphalt mixture, which replaces fine minerals and helps in the deicing process. To validate the performance of asphalt mixture with MFL content, some indoor tests were conducted. We investigated the field deicing capacity of the asphalt mixture, and compared the performance of several asphalt mixtures with different MFL contents. The results showed the following: (1) under the same gradation, the automatic long-term snowmelt asphalt mixtures displayed better anti-rutting performance, and the MFL content only slightly affected the low-temperature performance of the asphalt mixture; and (2) the moisture stability of three kinds of asphalt mixture met the specification requirement, although it decreased with the increase in MFL content. Based on the indoor and outdoor deicing effects of the asphalt mixture, more MFL contents in the asphalt mixture could result in better pavement deicing.

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Key words*: Automatic long-term snowmelt asphalt mixture; Road engineering; Test and analysis; Thermal stress-restrained specimen test (TSRST).*

Introduction

In recent years, the effect of low-temperature ice and snow-freezing damage on road traffic has increasingly grown. For instance, China suffered an unprecedented low-temperature ice and snow-freezing damage in early 2008, which has greatly affected people’s production and living [1]. Usually, more manpower and material resources are invested to clear the snow and ice, whereas the widespread adoption of dusting deicing salt and snow-melting agent leads to a certain degree of hazard to the pavement structures, environment, and human health [2]. Therefore, the search for a time-saving, easily applicable, safe, and environment-friendly ice- and snow-removal technology has become an important research subject.

In the 1960s, Switzerland, Germany, and some other European countries began to research and develop active snow- and ice-melting bituminous pavement. In the late 1970s, Japan introduced technologies and implemented automatic long-term snowmelt asphalt pavement in the Yamagata Prefecture in 1986 for the first time, which was promoted for application and dissemination [3]. Its representative product is Mafilon (abbreviated as MFL), a powdered material that has a similar gradation (Table 1) to mineral powder, which can replace a part or all of the mineral powders in bituminous mixture. Bituminous pavement mixed with MFL plays an active role in melting ice and snow, which can be applied in steep sections, tunnel entrances, bridge decks, mountainous highways, and other sections that easily accumulate snow. It can effectively prevent snow accumulation and ice covering on the pavement. In addition, the use of active snowmelt bituminous pavement on urban intersections and other sections that require vehicle deceleration or sharp turning can prevent vehicles from brake slipping during snowy days.

Action Mechanism of Automatic Long-term Snowmelt Asphalt Mixture

Basically, MFL adopts the igneous rock inclusion salt in the porous structure, grounded into powder particles to replace the mineral powder in the mixture to disperse fully the salt into the mixture. By virtue of osmotic pressure, capillary phenomenon, and the effect of friction of moving vehicles, the salt in the MFL material gradually precipitates from the narrow space inside the bituminous mixture with higher salt concentration into the pavement surface with lower salt concentration. It then rapidly dissolves in the water so that the liquid-phase vapor pressure of the water decreases, but the solid vapor pressure of the ice remains invariant. The solid–liquid vapor pressure balance principle of the ice and water mixture is attained when the snow begins to melt, which prevents and delays the freezing of the pavement in winter, resulting in deicing effect. In addition, the volume of porous materials remains unchanged after the precipitation of salt, which avoid the hazards caused by the precipitation of the effective components in the mixture. Its major action principle is shown in Fig. 1.

Pavement Performance Test of the Automatic Long-term Snowmelt Asphalt Mixture

The automatic long-term snowmelt asphalt mixture is manufactured from powdered MFL material, replacing a certain portion or all the mineral powders in the bituminous mixture. The incorporation of MFL produces a certain effect on the performance of bituminous mixture. This study adopted different test methods for laboratory tests on the bituminous mixture using three kinds of MFL replacement ratios (0%, 50%, and 100%) to test its

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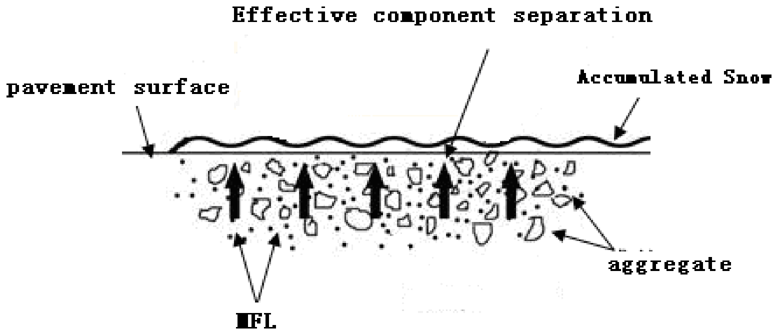


Fig. 1. Deicing Diagram of the Automatic Long-term Snowmelt Asphalt Mixture.

Table 1. The Comparison of the Physical Properties of Mineral Filler and MFL.

Test Items	Mineral Filler Test Results	MFL Test Results
Appearance	No Lumps	Powder-like Substances Similar to the Mineral Powder
Apparent Density (g/cm^3)	2.512	2.269
Moisture Content (%)	0.40	0.20
Salt Content (%)	-	55.9
pH	-	8.2
Particle Size Range (%)	-	-
<0.6 mm Particle Content	100	100
<0.15 mm Particle Content	92	84.3
<0.075 mm Particle Content	76	69.5
Main Chemical Components	Pulverized Limestone and Other Igneous Crushed Stone.	Sodium Chloride, Silicon Dioxide, Magnesium Oxide, Calcium Oxide Etc. The Active Ingredient is Sodium Chloride, Accounting for About 55%.

Table 2. Test Results of SBS Modified Bitumen Technical Properties.

Test Items		Specification Requirements	Test Results
Penetration (25℃, 5 s, 100 g) (0.1 mm)		40–60	58.6
Penetration Index		≥0	0.83
Ductility (5℃, 5 cm/min) (cm)		≥20	35
Softening Point $T_{R\&B}$ (℃)		≥60	78
Kinematic Viscosity (135℃) (Pa·s)		≤3	2.2
Flash Point (℃)		≥230	308
Solubility (%)		≥99	99.82
Poor Segregation and Softening Point (℃)		≤2.5	2.0
Recovery of Elasticity (25℃) (%)		≥75	100
TFOT	The Mass Loss is Not Greater Than (%)	±1.0	-0.12
	Penetration Ratio (25℃) (%)	≥65	78.6
	Ductility (5℃, 5 cm/min) (cm)	≥15	17

high-temperature, low-temperature, and water-stability performance. In relation to the comparison of the effect of MFL materials under different replacement ratios on the pavement performance variations of the bituminous mixture, we also tested the snow- and ice-melting effects of the active long-term snowmelt bituminous mixture.

Raw-material Properties and Test Graduation

MFL is added into the bituminous mixture as a filler to replace the mineral powder in the bituminous mixture, which is an important part in the automatic long-term snowmelt asphalt mixture. Its technological properties exert a large effect on the properties of the mixture. Table 1 showing comparison of the physical properties of mineral filler and MFL.

In the test, the Donghai SBS modified asphalt was adopted; the mineral aggregate quality conformed to the requirements of the technical index stipulated in the “Technical Specifications for Construction of Highway Bituminous Pavement” (JTG F40-2004). In addition, we adopted the AC-13C coarse dense graduation, and the optimum bitumen aggregate ratio was 4.8%. The major technical indexes of the bitumen are shown in Table 2, and the test graduation is shown in Table 3.

Table 3. AC-13C Test Aggregate Gradation.

Mesh Size (mm)	16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Percentage (%)	100	98.4	73.7	48.4	32.6	23.1	17.4	13.5	9.3	6.2

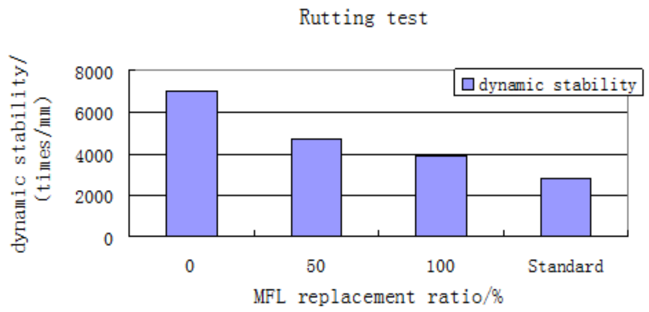


Fig. 2. Test Results of Dynamic Stability.

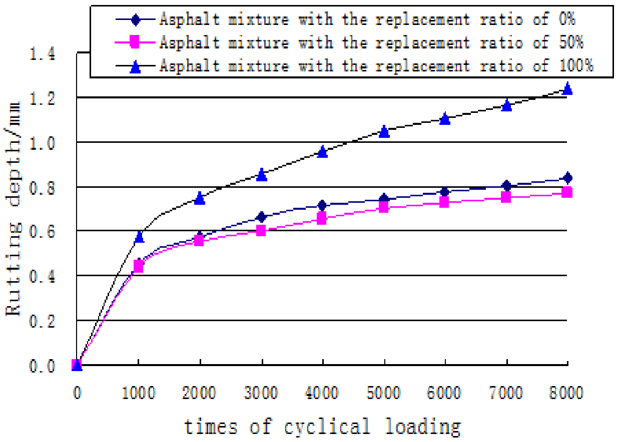


Fig. 3. Test Result of Rutting by APA.

Pavement Performance Test

High-temperature Performance Test

The wheel-tracking dynamic stability test is an engineering test method that simulates the actual wheel load that moves on the pavement and forms wheel tracks. The times of deformation test wheel traveling by generating 1mm wheel track after mixture specimen deformation enters into a stabilizing period when wheel tracking test for bituminous mixtures is carried out according to the 60°C temperature, calculated by times/mm. The test results are shown in Fig. 2.

Fig. 2 shows that the dynamic stability of the active snowmelt bituminous mixture decreased with increasing MFL replacement ratio. In the case of 100% mineral powder replacement by MFL material, the bituminous mixture retained its excellent high-temperature stability, and its dynamic stability was up to 3,851 times/mm, which complies with the current specification requirements (not less than 2,800 times/mm) [4].

Asphalt Pavement Analyzer (APA) Wheel-Tracking Test. The U.S. Strategic Highway Research Program (SHRP) proposes the use of Georgia's Asphalt Pavement Analyzer (APA) to conduct high-temperature wheel-tracking test. APA is designed to determine the high-temperature stability of the bituminous mixture by measuring the permanent deformation of the bituminous mixture specimen under 60°C high-temperature conditions and cyclical loading of 8,000 times [5–7]; the test results are shown in Fig. 3.

The APA wheel-tracking test results indicate no significant variation in the test results of the mixture without MFL compared with the mixture with added MFL that replaced 50% of the mineral powder. After 8,000 times of cyclical loading, the wheel-tracking depth was controlled to within 1.0 mm. In the case of the 100% mineral powder replacement in the bituminous mixture by MFL, the wheel-tracking depth was controlled to within 1.3 mm. The test results showed a certain consistency in comparison with the wheel-tracking dynamic stability test, which showed superior anti-wheel-tracking performance.

Low-temperature Performance Test

Currently, various test methods are used at home and abroad to study the low-temperature crack-resistance performance of the bituminous mixture. In accordance with the actual application situation in simulated pavement, the thermal stress-restrained specimen test (TSRST) can simulate the stress process of the thermal contraction cracking of bituminous pavement, which reflects the changes in temperature of the actual pavement and can comprehensively reflect the effect of various factors on the low-temperature performance of bituminous mixture [8, 9].

TSRST is a method adopted by the U.S. SHRP for evaluating the low-temperature anti-cracking performance of bituminous mixture.

In the test, we used the 40 mm × 40 mm × 220 mm prism specimens, which were packed in a fixture and firmly bonded with adhesive. The entire testing machine was placed inside an environmental cabinet, cooled down from the initial temperature of 5°C at a cooling rate of 10°C/h. The specimen was subjected to shrinkage deformation when cooled, but the computer automatically reloaded it for every shrinkage deformation of 0.002 mm to stretch the specimen to its original length until the load exceeded the maximum load of the specimen and it fractured. Thus, we were able to obtain four evaluation index results, including cracking temperature, cracking stress, turning-point temperature, and gradient. The cracking temperature could most properly evaluate the low-temperature performance of the bituminous mixture owing to its most stable evaluation index for low-temperature anti-cracking performance of the bituminous mixture [10].

The temperature–stress curve for the three kinds of bituminous mixture in TSRST is shown in Fig. 4, and the test results are shown in Fig. 5.

In accordance with the test data shown in Fig. 5, under the same graduation conditions, the cracking temperature of the three bituminous mixtures is similar, with a difference of less than 0.5°C. Thus, MFL dosage clearly has little effect on the cracking temperature of the bituminous mixture, indicating that the use of MFL material to replace the mineral powder in the mixture did not affect the low-temperature properties of the bituminous mixture.

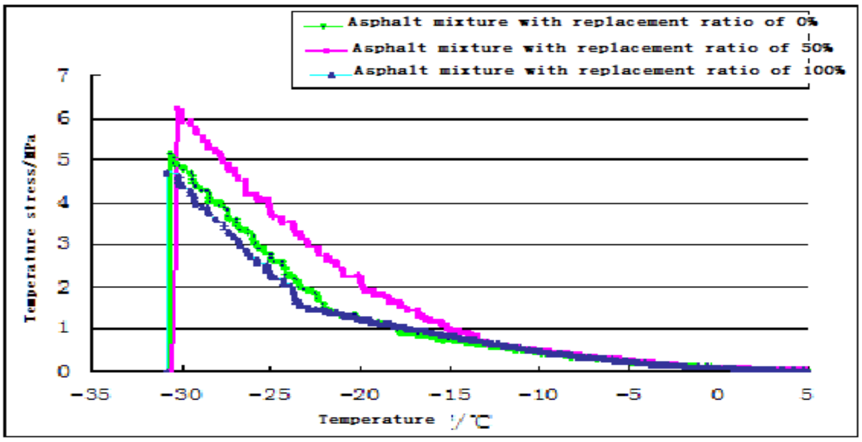


Fig. 4. Temperature–stress Curve of the Bituminous Mixture.

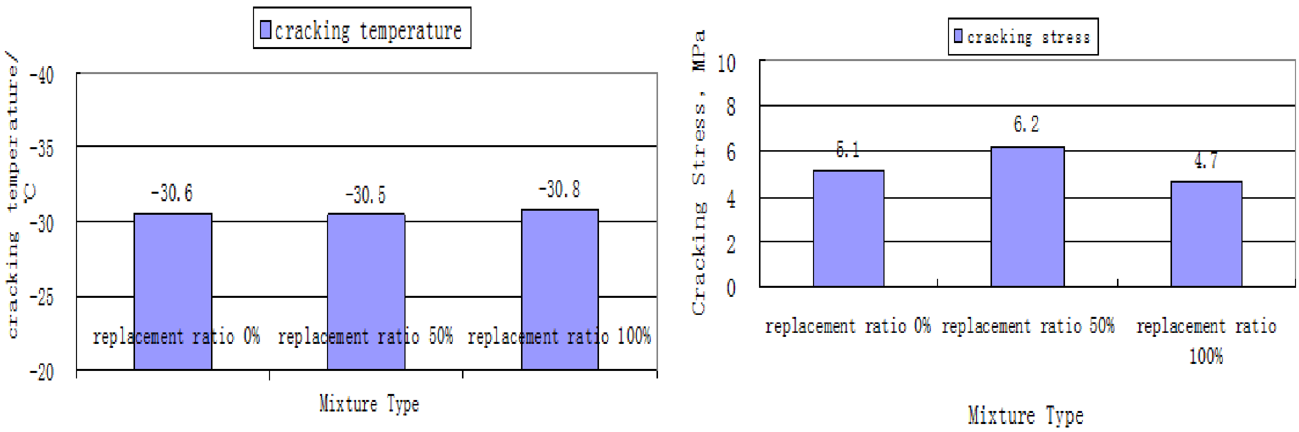


Fig. 5. TSRST Results of the Bituminous Mixture.

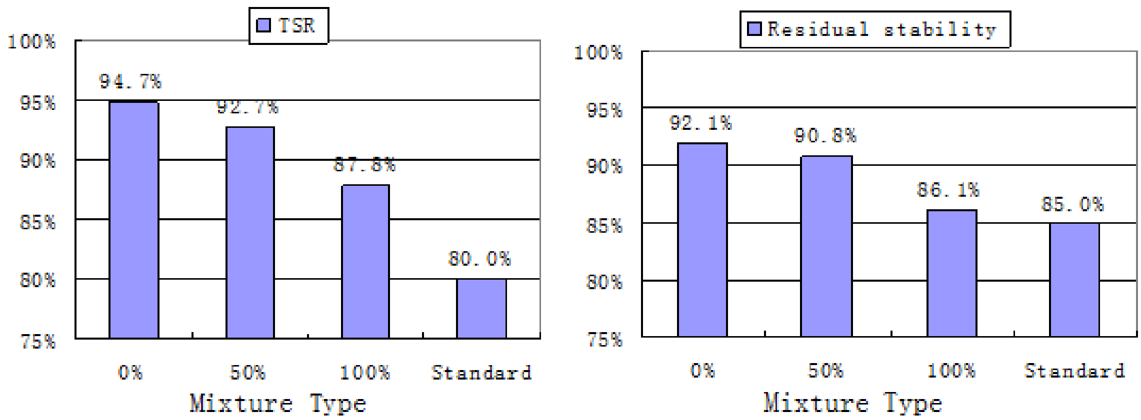


Fig. 6. Result of the Water-stability Test.

Water-stability performance test

Water damage is one of the main problems of bituminous pavement, which can happen either in frozen or rain-fed areas. Water damage can separate the asphalt from the aggregate, resulting in unconsolidation, peeling, potholes, and other problems on the pavement and causing serious harm to pavement performance [11]. The present study adopted the immersion Marshall test and freeze–thaw splitting test to conduct water-stability test for the three kinds of bituminous mixture; the test results are shown in Fig. 6, which indicated that the immersed residual stability and freeze–thaw splitting residual strength ratio decreased with the increase in the MFL replacement ratio. Specifically, no significant variation in the water stability of the mixture was observed with the 0% and 50% replacement ratios. However, the water stability of the mixture that used MFL to replace 100% of the mineral powder was slightly poor, although it still met the specification requirements.

To illustrate further the differences in water stability of the three

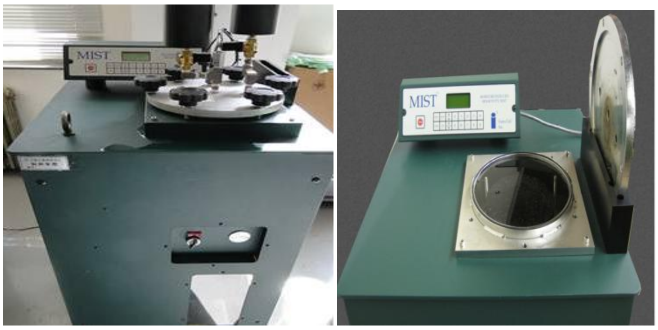


Fig. 7. MIST Test Equipment.

mixtures, considering the effect of hydrodynamic pressure on the bituminous mixture, the moisture-induced sensitivity test (MIST) water damage test apparatus manufactured in the United States was employed for the test in this study; the test apparatus is shown in Fig. 7. The test process was done as follows: first, we measured the bulk density of the specimen and placed it into the MIST test apparatus to perform 3,500 hydrodynamic pressure cycles at 50℃ and hydrodynamic pressure of 40 psi. Thereafter, we removed the specimen and placed it in the water at room temperature for 4 h; subsequently, we measured the bulk density of the specimen again. The difference was utilized to evaluate the water damage-resistant capability of the specimen. A 1.25% density variation was adopted as standard to evaluate the water damage capacity of the specimen. Because we have simulated the hydrodynamic pressure state exerted on the bituminous mixture specimen, we were able to provide a more realistic evaluation on the water stability of the bituminous mixture [12, 13]. The test results are shown in Table 4, which revealed that the three kinds of bituminous mixture have superior resistance to hydrodynamic pressure. In addition, the results indicated that the higher the MFL replacement ratio is, the greater is the change in the mixture density; thus, the MFL material has a significant effect on the water damage-resistant capacity of the bituminous mixture.

Evaluation of Snow- and ice-melting Effects

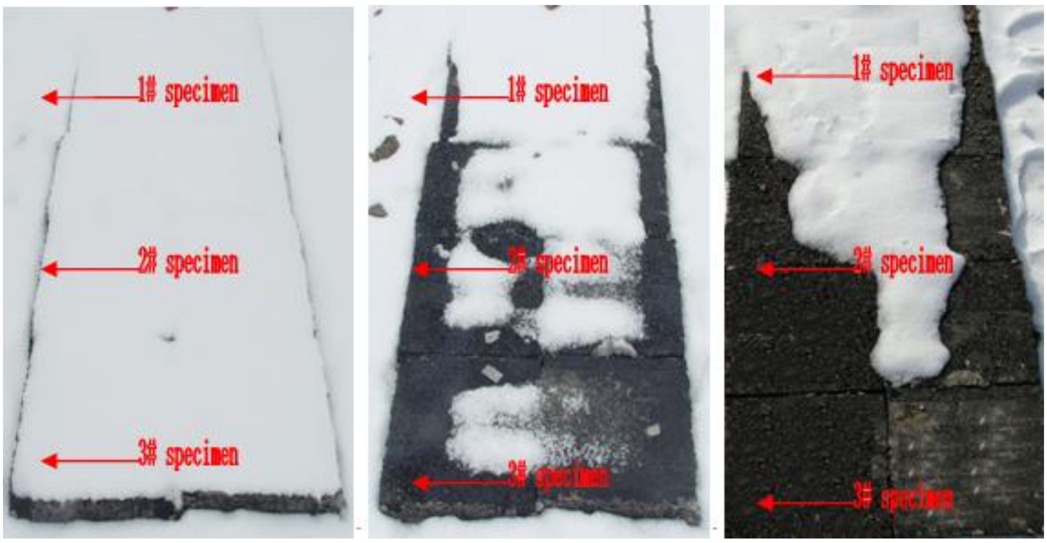
Table 4. Results of MIST.

Mixture Type	Changes In Bulk Density (%)	Standard Index (%)	Water Damage Resistant Capacity
No addition of MFL	0.13	1.25	Good
Replacement of 50% Mineral Powder by MFL	0.29	1.25	Good
Replacement of 100% Mineral Powder by MFL	0.68	1.25	Good

To evaluate the ice- and snow-melting effects of the active long-term snowmelt bituminous mixture, three kinds of indoor molding AC-13 bituminous mixture specimen with different MFL dosages were exposed outdoors after unmolding to observe their ice- and snow-melting effects. Meanwhile, we also studied the ice- and snow-melting effects of the active long-term snowmelt bituminous experimental pavement; the outdoor temperature was maintained from 3℃ to 8 ℃ throughout the snow-melting process.

The real-time snow-melting effect of the bituminous concrete pavement under three different MFL dosages is shown in Fig. 8. In particular, the MFL replacement ratios of 1#, 2#, and 3# specimen were 0%, 50%, and 100%, respectively. The ice- and snow-melting effects of the experimental pavement are shown in Fig. 9.

The Fig. 9 shows that, under certain temperature conditions, the active snowmelt bituminous pavement was able to melt the accumulated snow on the pavement and delay icing of the accumulated snow. Fig. 8 shows that the addition of MFL material in the bituminous mixture was able to remove quickly the snow and ice. In particular, the higher the MFL dosage is, the better is the snow- and ice-melting effect. To simulate the actual pavement situation in the highway, the ordinary bituminous pavement was distributed with a great deal of snow, and the active long-term snowmelt bituminous pavement was found to have a superior



(a) After snow (b) Two hours after snow (c) Four hours after snow

Fig. 8. Ice- and snow-melting Effects of the Laboratory-molded Specimen.

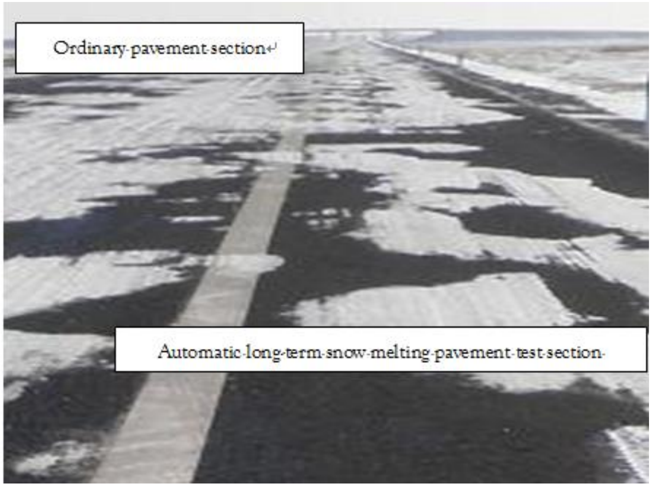


Fig. 9. Deicing Effect of the Automatic Long-term Snowmelt Pavement Test Section.

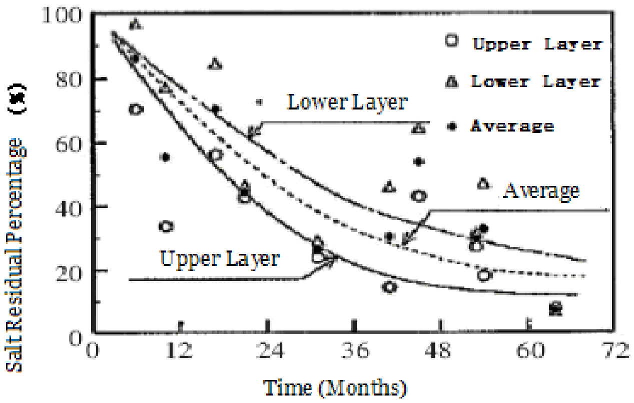


Fig. 10. Relationship Between Salt Residual Percentage and Time.

pavement exposure effect. Only a small amount of snow adhered to the ice on the bituminous pavement; thus, it can be quickly removed.

The ice- and snow-melting effects of the active long-term snowmelt mixture are due to its active ingredients that can gradually precipitate from the pavement, lowering the freezing point of the pavement. As long as salt exists in the MFL material of the bituminous mixture, its effect to lower the freezing point will be maintained. Therefore, the amount of remaining salt in the pavement is the main factor for the continuing function of the snow-melting pavement, and we need to investigate continuously the snow- and ice-melting effect of substantial engineering pavement. As the application of this bituminous mixture is currently uncommon in China, the study adopted the investigation data of the snowmelt bituminous pavement used in Japan [14].

Fig. 10 shows the salinity change data of a snowmelt pavement in Japan from 1990 to 1996, which indicate that the salt residual percentage declined against time for this pavement. After six years, the salt residual percentage gradually stabilized to 20% or so; however, it still possessed certain snow- and ice-melting capacity. Hence, the active snowmelt bituminous pavement has a long-term-effect property for snow and ice melting.

Conclusions

(1) The working principle of the active long-term snowmelt bituminous mixture is the replacement of mineral powder in the bituminous mixture using MFL material and enabling the salt to disperse fully in the mixture so that the salt in the MFL material gradually precipitate through osmotic pressure, capillary phenomenon, and friction effect on moving vehicles. Thus, this process could bring down the freezing point of the pavement to alleviate freezing of the pavement in winter and continue to achieve ice and snow melting.

(2) Under suitable gradation conditions, the high-temperature performance, low-temperature performance, and water stability of the active long-term snowmelt bituminous mixture are consistent with the bituminous mixture performance requirements prescribed in current specifications. With respect to the mixture with different MFL dosages, a good high-temperature performance is achieved, whereas the low-temperature performance is substantially independent of the MFL dosage. The water stability decreases with increasing MFL dosage; thus, we should adopt an appropriate MFL material to replace the mineral powder in the bituminous mixture.

(3) In terms of the ice- and snow-melting effects of the bituminous mixture on the indoor and experimental pavement, the active long-term snowmelt bituminous pavement features satisfactory ice- and snow-melting effects. Simultaneously, the observation data of the active snowmelt bituminous pavement in Japan validate the long-term snow- and ice-melting properties of the bituminous mixture pavement.

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