Experimental study on road performance of asphalt mixture mixed with antifreeze

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Abstract. In order to ensure the fast and efficient snow removal of roads in winter, a kind of slow-release antifreeze combined with asphalt concrete is developed, and its road performance is studied. In this paper, a kind of antifreeze performance of AC-13 is developed, therefore, the low and high temperature performance, water resistance, damaging antifreeze performance of asphalt mixture are studied under different dosage of antifreeze. Based on the analysis of the performance evaluation of the road at the same time the climate suitability of different antifreeze, this paper studies changes of dosage of antifreeze antifreeze performance decay law of asphalt mixture. The results show that the water damage resistance, low and high temperature performance of the antifreeze mixture are decreased with the increase of the antifreeze dosage, but under the appropriate dosage, the performance of the asphalt mixture could meet the requirements of the specification, and the optimal dosage of AC-13 antifreeze is 5.5%.

1. Introduction
China's territory is vast. In the winter snow and ice season, China's north and western mountain roads are prone to snow and ice, the southern region is prone to freezing rain, which brings great danger road traffic. Snow and ice lead to the reduction of anti-skid performance of road surface, which on the one hand reduces the traffic efficiency and causes traffic congestion, on the other hand, it will cause serious traffic accidents and endanger people's property and life safety. Therefore, how to solve the problem of snow and ice on roads and guarantee the traffic efficiency and safety is an urgent problem for road workers [1]. At present, the main methods of anti-ice and snow removal in China include manual snow removal, mechanical snow removal and snow removal by sprinkling snow melting agent [2]. Manual snow removal and mechanical power snow removal are inefficient and they will hinder the traffic on the road in the process of snow removal. The snow removal method of spreading snow melting agent is widely used because this kind of material is cheap, widely available and easy to operate and quickly melt the snow cover in a short time. Chlorine salt snow melting agent is a kind of snow melting agent mainly used in various countries, which has the advantages of fast snow melting efficiency and appropriate price, etc.. However, with the development of time, the chloride ions in the
chlorine salt snow melting agent will seriously corrode the reinforced concrete structure and cause irreversible pollution to the ecological environment [3].

In recent years, China has carried out research on the technology of active snowmelt asphalt pavement [4], and the slow-release self-snowmelt pavement adopts the special treatment of antifreeze, which can continuously precipitate the effective snowmelt components during the use of asphalt pavement and reduce the freezing point of pavement snow. Therefore, compared with the direct sprinkling of antifreeze (an active de-icing method), de-icing is carried out without manpower and material resources, which not only shortens the icing time, but also can melt snow and ice in real time, which can achieve de-icing effect with higher efficiency.

Currently, representative antifreeze products on abroad are mainly Mafilon (Japan) and Verglimit (Switzerland) [5]. However, the high price of Mafilon (MFL for short) makes it difficult to be promoted in a large range, and find that the road performance of mixtures mixed with corresponding products has a downward trend [6]. In this paper, the combination of domestic antifreeze and AC-13 is selected. The experimental study not only helps to develop domestic antifreeze with better snowmelt effect and road performance, but also forms a set of slow-release evaluation system of self-snowmelt asphalt pavement.

2. Raw materials and tests

2.1. Raw materials

70# asphalt is used in this test. The basic indexes of AC-13 modified asphalt are shown in Table 1. The basic physical indexes of asphalt, including penetration, softening point and elongation, are determined according to the relevant test procedures. The basic properties of the aggregate are shown in Table 2. The nominal maximum aggregate size for the mixture is 13.2mm. In this paper, a newly developed slow-release antifreeze is adopted, as shown in Figure 1. The basic properties of antifreeze are shown in Table 3.

The antifreeze was added to the melting snow and ice asphalt mixture by the method of equal volume substitution. The antifreeze content accounted for 4\%, 5\% and 6\% of the aggregate quality. The design gradation of asphalt mixture is shown in Table 4. Table 5 shows the Marshall test results. The target voidage is 3 - 7\% and the corresponding whetstone ratio is 3.5 - 5.5\%. Considering other properties, the ratio of whetstone is selected to be 5.1\%, and the corresponding properties of asphalt mixture are shown in Table 6.

| Test items          | Test results |
|---------------------|--------------|
| Penetration /0.1mm  | 74           |
| Ductility /cm       | >100         |
| Softening point /°C | 44.6         |

| Mineral aggregate | Apparent density | Bulk density | Bibulous rate |
|-------------------|-----------------|--------------|--------------|
| 9.5-16mm          | 2.923           | 2.873        | 0.60         |
| 4.75-9.5mm        | 2.970           | 2.904        | 0.77         |
| 2.36-4.75mm       | 2.913           | 2.838        | 0.91         |
| 0-2.36mm          | 2.890           | 2.790        | 1.24         |
| Ore powder        | 2.705           | /            | /            |
### Table 3. Basic properties of antifreeze.

| Index                      | Test results   | Index requirements |
|----------------------------|----------------|--------------------|
| Relative density           | 2.08 g/cm³     | ≥1.8               |
| Moisture content           | 0.3%           | ≤3                 |
| 2.36mm Pass rate           | 87.6%          | ≥85                |
| 1.18mm Pass rate           | 12.4%          | ≤18                |
| 20% Aqueous freezing point | -15°C          | ≤-14               |
| hardness                   | 45.3 N         | ≥35                |
| PH                         | 11.4           | 11-12              |
| 170°C Loss rate of heating mass | 0.2%          | ≤0.5               |
| Corrosion rate of carbon steel | 0.05 mm/a   | ≤0.1               |

### Table 4. AC-13 grading range.

| Mesh(mm) | 16.0 | 13.2 | 9.5  | 4.75 | 2.36 | 1.18 | 0.6  | 0.3  | 0.15 | 0.075 |
|----------|------|------|------|------|------|------|------|------|------|-------|
| Upper bound (%) | 100  | 100  | 85   | 68   | 50   | 38   | 28   | 20   | 15   | 8     |
| lower bound (%)  | 100  | 90   | 68   | 38   | 24   | 15   | 10   | 7    | 5    | 4     |
| Design gradation  | 100.0| 93.2 | 72.6 | 42.1 | 31.0 | 22.2 | 15.4 | 10.6 | 8.2  | 6.5   |

### Table 5. AC-13 design grading Marshall test results.

| AC-13 | Asphalt-aggregate ratio (%) | Gross volume density | Theoretical maximum density | Voidage (%) | Stability(kN) | Value(0.1mm) |
|-------|------------------------------|----------------------|----------------------------|-------------|---------------|--------------|
| 3.5   | 2.41                         | 2.578                | 6.5                        | 12.37       | 27.8          |
| 4.0   | 2.411                        | 2.557                | 5.7                        | 14.03       | 32.5          |
| 4.5   | 2.433                        | 2.540                | 4.2                        | 15.32       | 26.6          |
| 5.0   | 2.461                        | 2.545                | 3.3                        | 16.52       | 27.4          |
| 5.5   | 2.444                        | 2.506                | 2.5                        | 13.44       | 37.3          |
| Requirement       | /                            | /                    | 3-5                       | ≥8          | 15-40         |

### Table 6. Design gradation asphalt mixture properties.

| Mixing characteristic | Design results | Technical requirements |
|-----------------------|----------------|------------------------|
| Gross volume density  | 2.425          | /                      |
| Theoretical maximum density | 2.540      | /                      |
| Voidage (%)           | 3.1            | 3-5                    |
| Asphalt-aggregate ratio (%) | 5.1       | /                      |
| Ratio of filler bitumen | 1.1           | 宜 0.6-1.6             |
| Stability(kN)         | 16.52          | ≥8                     |
| Value(0.1mm)          | 27.4           | 15 - 40                |
2.2. **Determine the optimal antifreeze dose**

The preparation of antifreeze asphalt mixture is carried out, and the optimal content of antifreeze is determined based on the water stability of the mixture. In order to guarantee the melting effect and service life of ice and snow under the condition of meeting the requirements of the specification, the group with a large amount of antifreeze is selected. In this paper, the best antifreeze dose is determined mainly by the immersion Marshall test and freeze-thaw splitting test.

(1) Immersion marshall test: the water stability of asphalt mixture is evaluated by residual stability. The greater the residual stability, the better the water stability. The immersed water residual stability $MS_0$ is calculated according to formula (1).

$$MS_0 = \frac{MS_{1}}{MS} \times 100$$  (1)

The mixture mixed with antifreeze is compared with the mixture not mixed with antifreeze. The experimental results are shown in Table 7 below.

**Table 7. Immersion Marshall test of AC-13 mixtures.**

| Dosage | No Soak |     | Soak |     | Immersion residual stability % |
|--------|---------|-----|------|-----|-------------------------------|
|        | No. | Stability (KN) | Average (KN) | No. | Stability (KN) | Average (KN) |                      |
| 0%     | 1   | 16.44           | 16.45         | 4   | 15.08           |                | 92.8                 |
|        | 2   | 16.42           |                | 5   | 15.40           |                |                      |
|        | 3   | 16.5            |                | 6   | 15.32           |                |                      |
| 4%     | 1   | 16.86           | 16.46         | 4   | 14.73           |                | 88.3                 |
|        | 2   | 16.01           |                | 5   | 14.45           |                |                      |
|        | 3   | 16.52           |                | 6   | 14.40           |                |                      |
| 5%     | 1   | 15.18           | 15.68         | 4   | 13.10           |                | 87.0                 |
|        | 2   | 15.84           |                | 5   | 13.84           |                |                      |
|        | 3   | 16.01           |                | 6   | 13.98           |                |                      |
| 6%     | 1   | 14.01           | 14.36         | 4   | 11.57           |                | 78.8                 |
|        | 2   | 14.30           |                | 5   | 11.24           |                |                      |
|        | 3   | 14.76           |                | 6   | 11.11           |                |                      |
As can be seen from figure 2, with the increase of antifreeze dosage, the stability has a significant trend of decreasing. When the residual stability reached 5%, it meet the requirements of the specification. When the antifreeze dosage reaches 6%, the residual stability is lower than the requirements of the specification. It can be seen from the test that the stability of the mixture, especially the unsoaked stability, can be guaranteed under the appropriate dosage of antifreeze, but the stability of the mixture will be reduced beyond a certain range. Seen from the Figure 3, mixed with antifreeze mixes the soaking remnants stability than not adding sample, antifreeze admixture is 6%, the soaking remnants stability cannot meet the specification requirements. It shows that asphalt mixture with antifreeze can reduce the stability of soaking, which can indirectly show that the water stability index can be used to determine the optimum content of antifreeze.

(2) Freeze-thaw splitting test: the splitting strength of the specimens without freeze-thaw cycle and the splitting tensile strength of the specimens after freeze-thaw cycle are tested according to T0729-2000 method. The freeze-thaw splitting test strength ratio TSR is calculated in accordance with formula (2-4).

\[
TSR = \frac{R_{T2}}{R_{T1}} \times 100
\]

\[
R_{T1} = 0.06287 \frac{P_{T1}}{h_1}
\]

\[
R_{T2} = 0.06287 \frac{P_{T2}}{h_2}
\]

Table 8. Freeze-thaw splitting test of AC-13 mixture.

| Dosage | No. | Cleavage strength (Mpa) | Average (MPa) | No. | Freeze-thaw splitting strength (Mpa) | Average (MPa) | Freeze-thaw splitting strength ratio |
|--------|-----|-------------------------|---------------|-----|------------------------------------|---------------|-----------------------------------|
| 0%     | 1   | 1.286                   | 1.313         | 4   | 1.1459                             | 1.178         | 89.7                              |
|        | 2   | 1.3438                  |               | 5   | 1.1093                             | 1.085         |                                   |
|        | 3   | 1.3098                  |               | 6   | 1.2802                             |               |                                   |
| 4%     | 1   | 1.214                   | 1.284         | 4   | 0.9393                             | 1.085         | 84.5                              |
### Table 1

| %  | 2     | 3     | 5     | 6     |
|----|-------|-------|-------|-------|
| 5% | 1.3478| 1.290 | 1.1228| 1.1935|
| 6% | 1.999 | 1.2247| 0.964 | 80.5  |

**Figure 4.** Trend chart of freeze-thaw splitting strength under different dosage.

**Figure 5.** Freeze-thaw splitting strength ratio under different dosage.

It can be seen from Figure 1.4, the mixture cleavage strength is reduced with the increase of antifreeze content. Hence, the mixture of freeze-thaw splitting strength ratio decreases, and the reduction increases gradually. Especially when the dosage of more than 5%, the reduction range is even greater. All shows that antifreeze can guarantee the cleavage strength of asphalt mixture on certain dosage range, otherwise otherwise the strength will be unstable and destroyed. As can be seen from Figure 1.5, adding antifreeze can reduce the freeze-thaw splitting strength ratio of the mixture. Therefore, on the premise of ensuring water stability, the amount of antifreeze should be appropriately reduced, or effective measures should be adopted to improve the freeze-thaw splitting strength of the mixture. Based on the above water stability test results, for AC-13 asphalt mixture, the interpolation method was used to determine the optimal content of domestic antifreeze is 5.5%.

### 3. Road performance test

As an additive, antifreeze will change the performance of asphalt mixture. At the same time, in the process of use, the slow-release self-melting snow asphalt pavement is subject to environmental
factors and repeated loads of vehicles for a long time, so the functionality and durability of this mixture are required to meet the requirements of standard use \cite{7,10}. Water stability test in title 1.2 has been verified. It is necessary to verify the high temperature performance and low temperature performance of the mixture with new materials in the pavement structure, and check whether it conforms to the requirements of relevant specifications.

3.1. Rut test
The high temperature performance test is to verify the deformation resistance of asphalt mixture under load. The rutting specimen is made 300mm*300mm*50mm according to the specification. The test temperature is 60°C while the wheel pressure is 0.7Mpa, and the dynamic stability is taken as the high temperature performance evaluation index. The dynamic stability is calculated in line with formula (5).

$$DS = \frac{(t_2-t_1) \times N}{d_2-d_1} \times C_1 \times C_2$$ \tag{5}$$

The rutting test is conducted at 60±1°C and 0.7±0.05mpa at 5.5% antifreeze content to test the high-temperature stability of the asphalt mixture. The experimental data are shown in Table 9.

| Specimen type          | No. | Dynamic stability, time /mm | Average, time /mm |
|------------------------|-----|-----------------------------|-------------------|
| No antifreeze          | 1   | 3882                        | 3747              |
|                        | 2   | 3598                        |                   |
|                        | 3   | 3762                        |                   |
| 5.5% antifreeze        | 1   | 2937                        | 2856              |
|                        | 2   | 3058                        |                   |
|                        | 3   | 2574                        |                   |

As can be seen from the experimental results, anti-freezing dynamic stability of asphalt mixture for 2856/mm can meet the requirements of the performance of modified asphalt mixture at high temperature. The design of AC-13 mixture has better high temperature stability, the domestic antifreeze performance of the mixture at high temperature studied in this project can meet the requirements of the current specification, thus paving antifreeze pavement can be used for promotion.

3.2. Trabecular bending test
The trabecular bending test is to verify the resistance of asphalt mixture to low-temperature cracks. The trabecular specimens are made according to the specification requirements of 250mm*30mm*25mm. The test temperature was -10°C, and the bending strain is used as the low temperature performance evaluation index. The maximum bending strain of the specimen is calculated according to the t0715-1993 method, and the formula (6-8) is used to calculate the maximum bending strain. The content of antifreeze was 5.5%. The test results are shown in Table 10 and Table 11, and the trabecular sample is shown in Figure 6.

$$R_B = \frac{3LP_B}{2bh^2}$$ \tag{6}$$

$$\varepsilon_B = \frac{6hd}{L^2}$$ \tag{7}$$

$$S_B = \frac{R_B}{\varepsilon_B}$$ \tag{8}$$
Left: normal ac-13 asphalt mixture  
Right: antifreeze asphalt mixture  

**Figure 6.** Trabecula after low temperature bending test

### Table 10. Test results of AC-13 mixture without antifreeze.

| No. | Largest load (kN) | Across the deflection (mm) | Bending tensile strength (MPa) | Stiffness modulus (MPa) | Failure strain (με) |
|-----|-------------------|---------------------------|-------------------------------|------------------------|-------------------|
| 1   | 0.96              | 0.462                     | 7.72                          | 3165.7                 | 2439.4            |
| 2   | 0.921             | 0.470                     | 7.47                          | 3026.8                 | 2467.5            |
| 3   | 0.96              | 0.468                     | 7.72                          | 3125.1                 | 2471.0            |
| 4   | 0.965             | 0.461                     | 7.78                          | 3205.7                 | 2427.2            |
| 5   | 1.02              | 0.473                     | 8.18                          | 3274.4                 | 2497.4            |
| 6   | 0.95              | 0.476                     | 7.71                          | 3076.8                 | 2506.1            |
| Average | 0.963          | 0.468                     | 7.76                          | 3145.8                 | 2468.1            |

### Table 11. Test results of AC-13 mixture containing antifreeze.

| No. | Across the deflection (mm) | Bending tensile strength (MPa) | Stiffness modulus (MPa) | Failure strain (με) |
|-----|---------------------------|-------------------------------|------------------------|-------------------|
| 1   | 0.321                     | 5.5                           | 2657.8                 | 2069.4            |
| 2   | 0.352                     | 4.76                          | 2413.5                 | 1972.2            |
| 3   | 0.342                     | 5.23                          | 2895.5                 | 1806.3            |
| 4   | 0.335                     | 5.44                          | 2834.3                 | 1919.3            |
| 5   | 0.35                      | 4.17                          | 2256                   | 1848.4            |
| 6   | 0.349                     | 4.06                          | 2208.7                 | 1838.2            |
| Average | 0.342          | 4.57                          | 2544.3                 | 1909.0            |

According to the bending test results at low temperature, as shown in table 10-11, the maximum bending strain of asphalt mixture containing antifreeze decrease significantly. When the content of antifreeze is 5.5%, the maximum bending strain is 1909 constant <2000 constant, which cannot meet the requirements of the current specifications. However, for the antifreeze asphalt mixture itself, it effectively reduce the freezing point and prevent the formation of thin ice at about 0℃. Therefore, the low-temperature bending strain index of the antifreeze asphalt mixture can be appropriately reduced. On the one hand, the low temperature performance of antifreeze asphalt mixture shall decrease because the antifreeze components on the specimen surface dissolve out in the process of cutting the trabecula and curing at low temperature. Therefore, when loading, the trabecula is more likely to break than the asphalt mixture without antifreeze. On the other hand, with the precipitation of antifreeze, the porosity of the sample increases, resulting in the decline of the low temperature performance of the mixture.

### 4. Conclusions
With the increase of the amount of antifreeze, the water stability, low temperature performance and high temperature performance of the antifreeze mixture are all reduced, that is, the addition of antifreeze will reduce the road performance of the mixture. According to the investigation, Japanese
MFL and lulimei products also have a certain degree of adverse impact on the road performance of the mixture. Domestic antifreeze and lulimei products have similar impact on the high temperature performance, and both meet the requirements of the current specifications. In this paper, water damage resistance test, high temperature performance test and low temperature performance test are carried out for asphalt mixture mixed with antifreeze. The tests conclude that for ac-13 modified asphalt mixture, the optimal content of antifreeze is 5.5%.

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