Comparison of the Effect of Different Anti-freeze Additives on the De-Icing Asphalt Mixtures

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ABSTRACT: Snow/ice Self-melting pavement is a new kind of pavement with asphalt mixtures containing anti-freeze additives. In this research, three kinds of anti-freeze additives (IB-A, IB-B and IB-C) were applied. IB-A is a chloride salt that contains four substances and IB-B is a sulfonate including two substances. IB-C is a kind of Phase change material. The performance of asphalt mixtures were evaluated by using a series of laboratory tests, such as high temperature resistance, low temperature crack resistance and moisture resistance. Furthermore, based on the surface contact mechanism relationship between ice and pavement surface, a test instrument was developed and a new method was proposed to evaluate snow/ice melting efficiency. The test results show that the asphalt mixture with IB-A has the highest snow/ice melting efficiency and IB-C has no difference with the control group. To balance the performance and snow/ice melting efficiency, the optimum anti-freeze filler content were determined and proposed to apply in the Zhangcheng highway pavement de-icing engineering.

KEYWORDS: Functional pavement; de-icing asphalt mixture; anti-freeze additives; snow/ice self-melting; materials performance

INTRODUCTION

The most northern area of China belongs to seasonal frozen area, in winter, snow and ice on asphalt pavement can cause skid resistance decline sharply, causing amounts of traffic accident [1, 2]. Transport management agencies have spent lots of money to remove snow and ice suppression. Both in home and abroad, some passive snow removing techniques like artificial or mechanical snow cleaning/spreading deicing salt were widely used. But it is devastating for pavement structure with artificial or mechanical snow removing techniques, and after snow melting, excessive salt concentration will destroy the stabilization of surrounding environment [3, 5]. Compared with hydraulic snow melting, surface snow melting coating, pre buried carbon fiber baseband and some other active anti-freeze techniques [6, 8], anti-freeze asphalt mixture process simple, easy to implement, and owns good performance so it is become the hot spot in road research area [9, 10].
At the 20th century 70’s, to ensure the transport safety and prolong the road service, the active anti-freeze techniques have been researched thoroughly in Japan [11]. In China, the research on salt anti-freeze road was carried out late and active snow melting techniques were hooked on foreign import like LULiMei, MFL etc. in which NaCl or CaCl$_2$ is the major ingredient. Among the research, LI Fupu et al. [12] thoroughly validated the mixture performance in which mineral powder was partly or fully replaced by MFL and conducted the melting ability test indoor or outdoor; XueZhongjun et al. [13] have studied the performance of salt asphalt mixture and pointed out that under the reasonable condition of raw material and grading, the salt anti-freeze mixture owns a good performance; Tan Yiqiu et al. [14] developed ice membrane and road surface adhesion force evolution system. Generally from previous literature, the potential drawbacks of anti-freeze asphalt mixture are their low temperature and moisture damage performance can’t meet the actual need and lacking of anti-freeze evolution. This study primary compares the influence of three kinds of anti-freeze additives on road performance exactly low temperature performance and moisture damage resistance. The anti-freeze evolution was based on interfacial shear resistance strength index. The conventional road performance test includes high temperature stability, low temperature crack resistance and moisture resistance.

**MATERIAL AND MIXTURE DESIGN**

**Raw material**

Asphalt binders on this study were modified SBS asphalt which is manufactured by Beijing Municipal Road Bridge Building Material Group Co. LTD. Some properties were test based on Standard Test Methods of Bitumen and Bituminous Mixture for Highway Engineering (JTG E20-2011) and test results are shown in Table 1.

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Measured value</th>
<th>Code value</th>
<th>Test method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (15ºC)</td>
<td>g/cm$^3$</td>
<td>1.011</td>
<td>-</td>
<td>T0603</td>
</tr>
<tr>
<td>Penetration (25ºC, 5s, 100g)</td>
<td>1/10 mm</td>
<td>75</td>
<td>60-80</td>
<td>T0604</td>
</tr>
<tr>
<td>Soften point</td>
<td>ºC</td>
<td>88.6</td>
<td>≥55</td>
<td>T0606</td>
</tr>
<tr>
<td>Ductility (5ºC, 5cm/min)</td>
<td>cm</td>
<td>44</td>
<td>≥30</td>
<td>T0605</td>
</tr>
<tr>
<td>Dynamic viscosity (135ºC)</td>
<td>Pa.s</td>
<td>2.07</td>
<td>≤3</td>
<td>T0625</td>
</tr>
<tr>
<td>Flash point</td>
<td>ºC</td>
<td>260</td>
<td>≥230</td>
<td>T0611</td>
</tr>
<tr>
<td>Penetration index (PI)</td>
<td></td>
<td>0.036</td>
<td>≥-0.4</td>
<td>T0604</td>
</tr>
<tr>
<td>Test on residue from rolling thin film oven</td>
<td>mass loss</td>
<td>%</td>
<td>0.04</td>
<td>T0609</td>
</tr>
<tr>
<td>Penetration ratio</td>
<td>%</td>
<td>82</td>
<td>≥60</td>
<td>T0609</td>
</tr>
<tr>
<td>Ductility (5ºC, 5cm/min)</td>
<td>cm</td>
<td>28</td>
<td>≥20</td>
<td>T0609</td>
</tr>
</tbody>
</table>
The coarse and fine aggregate adopted in this study are manufactured by Changping Beijing, and its properties meet the requirements of Technical Specification for Construction of Highway Asphalt Pavements (JTG F40-2004). To compare anti-freeze effect, three kinds of anti-freeze additives are applied. They are IB-A, IB-B, IB-C. The appearance of additives is shown in Fig1.

![Anti-freeze substances appearance](image)

**Figure 1. Anti-freeze substances appearance.**

**MIXTURE DESIGN**

**Grading design**

Because the additives have similar particle size with mineral powder, so it could be as filler incorporate with asphalt mixture. Taking anti-freeze function and road performance into account, additives are added to mixture by a percentage of gross mass. The objective void is controlled in 2.5%-3.5% and specific grading is shown in Table 2.

<table>
<thead>
<tr>
<th>Type</th>
<th>Sieve pass ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>16</td>
</tr>
<tr>
<td>Anti-freeze AC-13</td>
<td>100</td>
</tr>
</tbody>
</table>

**Table 2. Composite grading of salt anti-icing asphalt mixture.**

Determination of optimum asphalt-aggregate ratio

This study adopts 2%、4%、6% (percentage of additives mixing amount and aggregate mass) three kinds of additive mixing amount. Referring to criterion, the optimum asphalt-aggregate ratio is determined by Marshall Test. Control the actual asphalt-aggregate ratio at 2.5%-3%.

**ROAD PERFORMANCE EVOLUTION**

**High temperature stability**

The high temperature stability is evaluated thorough a wheel tracking test. The specimen is a slab of which thickness is 50mm and both of length, width is 300mm. when wheel tracking test carrying out, the specimen slab is loaded by a repeated solid rubber tire with a contact pressure of 0.7Mpa at a speed of 42cycles per minute. Test results are shown in table 3.
Table 3. Road performance of different mixture types.

<table>
<thead>
<tr>
<th>Type</th>
<th>Mixing amount</th>
<th>Dynamic stability (cycles/mm)</th>
<th>flexural failure strain ($\mu\varepsilon$)</th>
<th>TSR (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC-13</td>
<td>0</td>
<td>4238</td>
<td>4234</td>
<td>95.6</td>
</tr>
<tr>
<td></td>
<td>2%IB-A</td>
<td>4432</td>
<td>4324</td>
<td>93.4</td>
</tr>
<tr>
<td></td>
<td>4%IB-A</td>
<td>4125</td>
<td>4580</td>
<td>86.7</td>
</tr>
<tr>
<td></td>
<td>6%IB-A</td>
<td>3985</td>
<td>4612</td>
<td>82.3</td>
</tr>
<tr>
<td></td>
<td>2%IB-B</td>
<td>4084</td>
<td>4250</td>
<td>83.1</td>
</tr>
<tr>
<td></td>
<td>4%IB-B</td>
<td>4062</td>
<td>4134</td>
<td>78.3</td>
</tr>
<tr>
<td></td>
<td>6%IB-B</td>
<td>3851</td>
<td>4322</td>
<td>68.4</td>
</tr>
<tr>
<td></td>
<td>2%IB-C</td>
<td>4128</td>
<td>4132</td>
<td>82.5</td>
</tr>
<tr>
<td></td>
<td>4%IB-C</td>
<td>3968</td>
<td>4212</td>
<td>72.3</td>
</tr>
<tr>
<td></td>
<td>6%IB-C</td>
<td>3901</td>
<td>4416</td>
<td>70.0</td>
</tr>
</tbody>
</table>

We can find that all test outcomes satisfy criterion requirements (>2800 cycles /mm). As additives content increased, rutting resistance decline. With 2% additives, mixture having IB-A inside owns the best dynamic stability which is 4432. Under 6% additives condition, the dynamic stability of mixture with IB-B is lower 4.6% than the mixture with IB-A, above all, there is no adverse effect with the addition of anti-freeze additives.

Low temperature crack resistance

Three point beam bending test was used as the evolution of low temperature performance of asphalt mixture. Test temperature was settled at -10ºC. Specimen size is 50 mm $\times$ 50 mm $\times$ 250 mm. The failure strains at failure are shown in table 3.

Firstly, all results meet the least requirement of criterion ($\mu\varepsilon$ >3000). Mixture have the best low temperature crack resistance with 6% IB-A, and with 6% IB-A, the flexural failure strain of mixture is 4612. Mixture with different mixing amount of IB-B shows there is no difference of low temperature performance between general asphalt mixture and anti-freeze asphalt mixture. The flexural failure strain with different mixing amount of IB-B is 4250, 4134, 4322 respectively. As the results’ trend is going up, indicating that as the content of IB-C raise, the low temperature performance of mixture is better. Above all, anti-freeze asphalt mixtures have favorable low temperature performance.

Moisture resistance

In this study, TSR test is applied. The high of standard Marshall Specimens is 63.5 $\pm$ 1.3mm and the diameter is 101.5mm. According to the criterion, the dry sample of experimental group was firstly saturated into the water for 0.5h, and then saturated specimens were conditioned at -18ºC for 24h. At last, put specimens in the water bath at 60ºC for another 24h. The test is conducted by a splitting test instrument with the loading speed of 50mm/min. The results of TSR test are shown in table 5.
The required minimum TSR value is 80%. It is observed that the TSR values of mixtures with 4% IB-B, 4%IB-C, 6%IB-B, and 6% IB-C are 78.3%, 72.3%, 68.4%, 70% respectively. Obviously, they are substandard. Test results show that the addition of CaCl$_2$ has less adverse impact than NaCl on combination of binders and aggregate. For IB-B, the prime function component is NaCl. IB-C is a phase change material. Comparison with another two types of anti-freeze mixture, its mixture moisture resistance behaves worst.

**ANTI-FREEZE EFFECT EVOLUTION**

Evolution method

To evaluate the actual effect of ice suppression of anti-freeze asphalt mixture, oblique shear specimen is designed. Design and manufacture slope asphalt mixture specimen. Put slope specimen into sleeves and reserve 1cm gap, injecting water into void, seal both sides of the sleeves and put the sleeves into freezing device. Primary freezing time is 16h, and then gets the specimen out from sleeves. Conduct surface ice removal until the slope interlayer just contains ice, carrying out another frozen about 8h. Test process and specimens can be seen in Fig.2 and Fig.3.

**Figure 2. Test process.**

**Figure 3. Specimen destroy.**

Evolution index

Use press machine loading axis compression on specimen until it damaged. Interface shear strength is calculated by equation (1).

$$\tau = \frac{P \sin \alpha \cos \alpha}{A} \quad (1)$$

P: the axial compressive stress; $\alpha$: slope angle; A: slope area of specimen.

Anti-freeze effect discussion

Specimen have been kept under three temperature, they are -10ºC, -15ºC, -20ºC respectively. Results can be seen in Fig. 4 to Fig.6.
Figure 4. Shear resistance strength values of mixture applied with IB-A.

Figure 5. Shear resistance strength values of mixture applied with IB-B.

Figure 6. Shear resistance strength values of mixture applied with IB-C.

In -10ºC, mixture applied with IB-A have lower shear resistance strength, they are 1.3Mpa, 0.9MPa, 0.7MPa respectively, under 6% IB-A condition, the shear resistance strength behaves worst. In -15ºC, compare with mixture containing 6% IB-B/6% IB-C, the addition of 6% IB-A cause shear resistance decline 55.8%, 61.2% respectively. It shows that mixture applied with IB-A still owns better anti-freeze ability. In -15ºC, from figures we can find that no matter how many IB-B/IB-C mixtures contain, the shear resistance strength is still in a higher level, and the line of results is nearly horizontal. By this condition, the mean value of shear resistance...
strength of mixture applied with different content of IB-B is 4.3MPa which is lower 11.8% than mixture containing IB-C. Meanwhile, the mean value of shear resistance strength of mixture applied different content of IB-C is just lower 4.7% than control group. It means mixture containing IB-B has poor anti-freeze performance and mixture applied with IB-C has no ability to hinder icing. In -20ºC, three lines are all horizontal, it represents there is no ability to inhibit the formation of ice. Above all, IB-A is recommended as anti-freeze functional constitutes for engineering.

CONCLUSIONS

This study has investigated the road performance and anti-freeze functional performance of three types asphalt mixture which contain IB-A/IB-B/IB-C. Also, to compare the difference on performance, choose mixture contains none additives as control group. Based on experimental results, conclusions are summarized as followings:

1. Through this research, three kinds of anti-freeze substance were chosen as ice depression functional component of asphalt mixture. Mixture applied with IB-A owns best road performance. When mixture was mixed with 4% IB-B/IB-C or 6% IB-B/IB-C, the moisture damage resistance can’t meet requirement of criterion.

2. Anti-freeze mixture owns ability to hinder ice formation. As the functional component usage increase, interface shear resistance strength decline obviously. With temperature decrease, anti-freeze performance weakens.

3. Mixture applied with 6% IB-A has the best anti-freeze effect and it still is functional under -15ºC. The mixture mixed with IB-C has the worst anti-freeze ability, it has no use when temperature is -15ºC or below. We recommended IB-A as anti-freeze component of zhangcheng highway pavement de-icing engineering.

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