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# Low temperature property and salt releasing characteristics of antifreeze asphalt concrete under static and dynamic conditions

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ABSTRACT

This research reports the low temperature properties and salt releasing characteristics of antifreeze asphalt concrete (AFAC) under different moisture conditions, such as static condition (wetting–drying cycles), static loading and dynamic loading conditions. Therefore, low temperature bending test and conductivity test were carried out to estimate the performance of antifreeze asphalt concrete. Results show that the low-temperature properties and salt releasing characteristics of antifreeze asphalt concrete are affected by salt content, continuously immersion time, wetting–drying cycles, solution temperature and, as expected, loading condition. A static/dynamic loading and conductivity test system was developed to simulate the traffic flow on pavement in working condition. It is revealed that loading condition also influences the salt releasing characteristics, especially that the dynamic loading will enhance the salt dissolving in water. In AFACs, the salt location is divided into three zones which are related with the salt releasing characteristics.



## 1. Introduction

Traditional asphalt mixtures have many kinds of disadvantages in applications (Buttlar and You, 2001; Qin et al., 2014; Wang, 2011). For instance, the snow or ice covered on asphalt pavement will significantly reduce the friction of the road surface (Conger, 2005; O'Keefe and Shi, 2006). To remove the snow or ice on pavement, antifreeze asphalt concrete containing chemicals, described as AFAC, is expected to become a world widely used technique to protect the traffic safety in winter (California Pavement Preservation Center, 2008; Giuliani, 2002; Sato and Hori, 2002; Zhang et al., 2011), besides the crumb rubber modified asphalt mixtures (Tan et al., 2013), conductive asphalt concrete (Liu and Wu, 2009) and hydronic pavement (Lee et al., 1984).

To understand the antifreeze performance of AFACs, previous measurements were developed, which can be mainly divided into direct methods and indirect methods, as shown in Fig. 1. In field applications, the $AgNO_3$ titration method is often used in new highway projects to confirm that the salts, mainly calcium chloride ($CaCl_2$), magnesium chloride ($MgCl_2$) and sodium chloride (NaCl), exist in the pavement layer (Araki et al., 1997; Zhang et al., 2011). In fact, the AFACs are used in winter event, especially snow-falling condition. The $AgNO_3$ titration method can't accurately show the antifreeze properties of AFACs. Thus, Zhang et al. (2011), Liu et al. (2014) and Li and Wang (2012) observed the snow-falling in cold winter where the AFACs plates were put outdoors on the ground covered with falling snow. Meanwhile, Liu et al. (2014) also modeled the snow-melting performance of AFACs. Giuliani et al. (2012) and Bai (2012) reported the ice-forming observations in which the AFAC samples with water on surface were put into an environmental box to observe the ice forming. These studies indicated that AFACs can provide at least three benefits in subfreezing temperature conditions: (a) delaying the ice layer formation between pavement and snow or ice, (b) facilitating snow removal or ice breakage, and (c) reducing the adhesion of ice/snow to pavement by melting the ice layer on the pavement surface covered with snow or ice above (Giuliani et al., 2012). However, the direct methods utilized previously are empirical and qualitative. Engineers and researchers need a quantitative measure with which to estimate the properties of AFACs. As a result, freezing point measured by thermocouples (Giuliani et al., 2012; Tan et al., 2013), BPN (British Pendulum Number) (Giuliani et al., 2012; Zhang et al., 2011), ice-broken coefficient (Qu et al., 2012), and adhesiveness (Bird, 1988; Farzaneh et al., 2008) was used to evaluate the antifreeze property of AFACs. Current research has indicated that the salt dissolved from AFACs into water could decrease the freezing point, then prevent freezing or melts the ice, which then makes the road safer. Therefore, the conductivity of the solution immersing from AFAC samples was adopted as an indirect method (Liu et al., in press; Wang et al., 2010). With this method, antifreeze temperature and antifreeze time were deduced via regression equations and the colligative properties of dilute solutions. After that, the observation proved the antifreeze properties estimating equations. Moreover,

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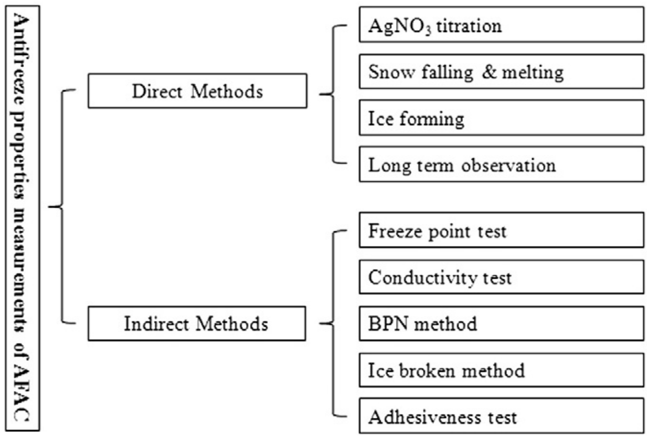


**Fig. 1.** Antifreeze property measurements of AFACs.

utilizing conductivity measurements, the salt releasing process in AFACs was divided into three steps during this experimental condition.

Previous studies found that moisture invading and water immersing are the most important detriments to the engineering performance (Özgan and Serin, 2013) and antifreeze properties of AFACs (Li and Wang, 2012; Makoto et al., 2006). Therefore, it is necessary to understand the influence of moisture on the performance of AFACs. Given that the general working condition of AFACs is in cold weather, the main objective of this research is to evaluate low temperature property and salt releasing characteristics of antifreeze asphalt concrete without loading and under static loading, dynamic loading conditions.

## 2. Raw materials and methods

### 2.1. Raw materials

SBS modified asphalt with a penetration of 71 (0.1 m at 25 °C, 100 g and 5 s), ductility of 37.06 (cm at 5 °C) and softening point of 89.5 °C (Guolin SK Asphalt Company Co., Ltd) is used in this research. All the samples were made up with basalt aggregate (2.92 g/cm$^3$), and machine-glazed limestone filler (2.83 g/cm$^3$). The antifreeze filler (2.17 g/cm$^3$), containing $SiO_2$, NaCl, $CaCl_2$, $Al_2O_3$, CaO etc., is provided by Xi'an Huabo Trans. Tech. Co., Ltd, China.

### 2.2. Methods

In this study, the AC-13 asphalt composition, a general type of mixture used in China of which there are 6.0 wt.% fillers (antifreeze filler and limestone filler included) and 94 wt.% basalt aggregates, was prepared. In the mixtures, the bitumen–aggregate ratio was 4.90 wt.%. The total amount of filler is 6 wt.%, but in some specimens, the mineral powder was replaced by antifreeze filler with the volume displacement method. Three prismatic specimens (250 × 30 × 35 mm) of each group were prepared according to the standard JTG E20-2011 for the bending test (T 0715–2011). Additionally, asphalt mixture blocks (300 × 300 × 50 mm) were produced (following T 0719–2011) for the salt releasing measurement.

The salt releasing characteristics are described by conductivity using DDS-11A with a platinum black electrode parameter (Ridao Scientific Instrument Co., Ltd in Shanghai, China). Here, the capability to transfer electrons in solutions or other dielectrics is defined as conductivity, the reciprocal of the electrical resistivity. This means the more ion the solution contains, the better ability to transfer electrons it will be. It is easily understood that a higher conductivity means much more chemicals dissolved in solution. The technical details of the salt releasing test could be found in the references (Liu et al., 2014; Liu et al., in press).

To investigate moisture sensitivity of the low-temp bending performance and salt release of AFACs, all the samples were immersed in water at room temperature under static and dynamic conditions. The experimental design is shown in Table 1. During the immersion process, conductivity of each AFAC was measured. Between each wetting–drying cycle, the samples were exposed to air for 24 h to evaporate the moisture in AFACs. At the beginning of the latter cycle, the AFAC surface was washed to minimize the effects of residual chemicals from the former cycle (Giuliani et al., 2012). After the wetting–drying cycle, the bending strength of prismatic samples was measured at −10 °C.

As reviewed above, the salt releasing characteristics of AFAC were analyzed under static loading and dynamic loading conditions, seeing Fig. 2. In this section, AFAC blocks, under a constant loading of 0.7 (±0.05) MPa, were immersed in 20,000 ml tap-water. The connecters between the block and the steel mold were sealed up with petroleum jelly to ensure that the salt would release only from the upper surface of the AFAC sample. A rubber wheel, with an external diameter of 200 mm, width of 50 mm and thickness of 15 mm, was used in this system. The running distance of the wheel was 230 (±10) mm with a speed of 21 (±0.5) revolutions/min. Considering the ion effects, the conductivity of the pure tap-water was demarcated and then was deducted from the measured data of AFACs. During the experiment, the temperature and rolling cycle were controlled by sensors connected with a computer.

## 3. Results and discussion

### 3.1. Influence on the low temperature bending strength

Fig. 3 shows the low temperature maximum bending strain of AFACs, which could be used to describe the anti-cracking properties of asphalt pavements (Tan et al., 2012). The results in Fig. 3(a) indicate that the bending strains of the asphalt mixtures were decreased with the addition of antifreeze filler. For example, the asphalt mixture without antifreeze filler obtained the best bending strain(4725.5), but that of AFAC with 6 wt.% antifreeze filler is the worst (2013). As shown in Table 1, all the samples were immersed water for 24 h at 20 °C. At this condition, the salt was absolutely dissolved into solution. Thus, micro-fissure will be formed in these exposed samples. As Wang et al. (2013) reported, the more antifreeze filler the AFAC contains, the more salt the sample will release. That is, after immersed in water, the AFAC with more antifreeze filler will obtain more micro-fissures. Under cold conditions, these fissures will cause the failure of pavement.

Fig. 3(b) provides details of the bending strain of AFAC with a constant proportion of antifreeze filler (5 wt.% as shown in Table 1), under repeated wetting–drying cycles. The result suggested that the bending strain of AFAC reached the bottom after 3 cycles, after which, the bending strain of AFAC increased. Considering the filler–bitumen ratio, this phenomenon seems understandable. In the first and second immersion cycles, the micro-fissures expressed a greater effect on the low temperature bending property. But after the third cycling, the effect of the filler–bitumen ratio becomes dominant with the salt releasing and the filler–bitumen ratio reduced. Therefore, the asphalt mixtures obtained improved anti-cracking property under low temperature

**Table 1**
Experimental design.

| Conditions | Antifreeze filler content (wt.%) | The number of cycles | Time, immersed in water (days) | Temperature (°C) |
|---|---|---|---|---|
| Static, without loading | 0, 2, 4, 5, 6 | 1 | 1 | 20 |
| | 5 | 1, 2, 3, 4 | 1 | 20 |
| | 5 | 2 | 1, 2, 3, 4 | 20 |
| | 5 | 2 | 2 | 20, 40, 60 |
| Static loading | 5 | 1 | – | 24.5, 35 |
| Dynamic loading | 5 | 1 | – | 24.5, 35 |