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Influence of the chloride-based anti-freeze filler on the properties of asphalt mixtures

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HIGHLIGHTS

- Asphalt mixtures containing anti-freeze filler with different particle size are researched in this paper.
- High- and low-temperature properties and the susceptibility to moisture damage are investigated, as well as conductivity test was carried out to research the influence on performance of the AFACs.
- Estimating model is developed based on the colligative property of dilute solution, and was proved with observation experiments.
- A better anti-freeze property of AFAC will be obtained in a little precipitation and high temperature conditions.

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ABSTRACT

This paper focused on the properties of asphalt mixtures containing anti-freeze filler (ICB-1, ICB-2, ICB-3 and ICB-4) with the volume replacement method. And the void content, high- and low-temperature properties and the susceptibility to moisture damage are investigated by experimental method. Based on the colligative property of dilute solution, a new evaluating model is developed, and proved with observation test. The result shows that the asphalt mixture containing a smaller particle obtains a better high- or low-temperature property, and water stability. Furthermore, it is believed that a better anti-freeze property of asphalt mixtures will be obtained in a little precipitation and high temperature conditions. Besides, in heavy event, a liquid layer appears between pavement and snow/ice, which would facilitate the mechanical removal of the snow or ice.

1. Introduction

Snow and ice control technology in winter has been an important issue in many countries currently, for too many accidents are resulted from the snow and ice on the pavement surface [1]. In order to offer a high level of service in cold winter, anti-freeze pavement, especially chloride-based anti-freeze asphalt concrete (described as AFAC), are developed, and widely used in the word [2–5].

In 1960s, chemical-based anti-freeze fillers were added in asphalt mixtures, obtaining a special self-deicing pavement [6], in Weitzerland, Germany, and some other European countries [7]. After that, chlorine salt, such as calcium chloride, sodium chloride and potassium chloride, are mixed in pavement, in order to allow vehicles circulation with the required safety. Due to the properties of decreasing the environmental pollution, as well as melting snow and ice proactively and providing the safety to vehicles and pedestrians, this type of roads are widespread used in Europe, Japan and China [8–10]. For example, the anti-freeze technique develops quickly by the researchers in Japan after 1970s [11]. And because of the great snow disaster in 2008 in China, pavements containing chemicals have been constructed in northwest and northeast China [12]. At present, there are three kinds of anti-freeze filler in applications, such as granular chemicals solidified with cement binder to replace the coarse aggregates [13], or modified by vegetable oil to take place of the fine aggregate [14], and chemical powder modified with resin to substitute the mineral powder [15]. The main differences of these fillers are the particle sizes that lead to the differences in replacing method. Therefore, Oskar [16] emphasized the importance of granular size of anti-freeze filler in their patent. In asphalt mixtures, the physical indicators, mechanical behavior and structure are affected by aggregate particle and the filler size [17,18]. However, in current literatures, few researches about the anti-filler size are reported.

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To simulate the anti-freeze properties of AFAC in winter, BPN (British pendulum number) was used to describe the skid level of specimens under different conditions. It is turned out that the BPN of AFAC almost unchanged. On the contrary, the BPN of those with no anti-freeze filler decreased [19]. At the same time, it is reported that STAP (Simulating Tester for Antifreeze Pavement) are carried out to evaluate the BPN of AFAC to simulate different winter events [9]. Results indicated that the BPN are affected by the anti-freeze filler contents. Recently, conductivity test is developed to measure the conductivity of solution containing chemicals (higher conductivity indicates more chemical dissolved and lower freezing temperature). Studies revealed that conductivities were different under various chemical contents, porosity and ambient temperatures [12,20]. Nonetheless, there is no direct method to estimate the anti-freeze performance of AFAC.

In this study, anti-freeze fillers, with four kinds of particle gradations, are mixed in asphalt mixtures based on the volume displacement method [20]. After that, high and low temperature stability and the resistance to water damage of AFAC were compared with the control sample without any chemical filler. In addition, the anti-freeze properties of AFAC were investigated by conductivity test and estimated based the colligative property of dilute solutions.

2. Experiments

2.1. Raw materials

2.1.1. Anti-freeze filler

Fig. 1 shows the description of the anti-freeze filler (IceBane^{TM}, produced by Xi'an Huabo Traffic Technology co., LTD, China.), used in this investigation, which contains chloride salt ($CaCl_2$, NaCl etc.) that is frequently used to melt snow and ice in winter on pavement, while the chloride salt is modified by a special hydrophobe. The density of the anti-freeze filler, with a light yellow appearance, is 2.17 g/cm^3. Table 1 ranks the fineness of the anti-freeze filler and mineral powder.

2.1.2. Binder and aggregate

In this research, SBS(1-C) modified asphalt, produced by Xi'an Guolin SK asphalt company co., Ltd., was used as the binder for all samples, as shown in Table 2. And the qualified aggregate (basalt), with a density of 2.92 g/cm^3, and mineral filler (machine-glazed limestone), with a density of 2.83 g/cm^3, were taken from Qinling Mountains in northwest-China.

2.1.3. Mixture

The composition of AC-13 mixtures, widely used in China designed by the Marshall test, was the control, as shown in Table 3. In the control mixture, the asphalt content is 4.90 wt.%, and the filler usage is 6 wt.%. As mentioned above, 5 wt.% of the mineral filler was replaced by anti-freeze filler by volume displacement method (replaced the equal volume of mineral powder with chemical filler). In this article, the replacement rate was 83.3% by volume. Therefore, the real content of the mineral filler was 1 wt.% in AFAC (described as ICB-1, ICB-2, ICB-3 and ICB-4 below).

Table 1
Fineness of anti-freeze filler and mineral powder.

Marked number	Passing rate (%)				
Sieve size (mm)	1.18	0.60	0.30	0.15	0.075
ICB-1	100	99.07	89.17	51.25	21.39
ICB-2	100	98.60	92.82	62.24	43.95
ICB-3	100	98.40	92.49	72.38	55.17
ICB-4	100	99.23	95.11	90.12	78.50
Mineral powder	100	98.04	95.51	90.24	78.33

2.2. Specimen preparation

In the experiment, the aggregates were mixed for 30–40 s, and heated at about 160 °C, which is ordinary for producing asphalt mixture. Subsequently, the liquid asphalt binder at about 160 °C was added into mixture and mixed for 60 s, and then, the mineral powder was added. After 60 s mixing time, the chemical filler was delivered into the semi-finished products of AFAC and mixed till resulting in a well coated and evenly distributed mixture. Afterwards, the hot mixtures were placed in steel frames and compacted at 145 °C to attain specimens, such as a Marshall specimen (101.6 mm × 63.5 mm), a block (300 mmm × 300 mmm × 50 mmm) and a prismatic (250 mm × 30 mm × 35 mm), according to the standard JTG E20-2011 (Standard test methods of bitumen and bituminous mixtures for highway engineering), which is the national standard of China. After this, the rutting test (T 0719-2011), freeze–thaw splitting test (T 0729-2000) and bending test (T 0715-2011) were carried out.

2.3. Conductivity test

The physical significance of conductivity is the capability to transfer electrons in solutions or other dielectrics, which is the reciprocal of the electrical resistivity. Therefore, the more ions in solutions or more chemicals were dissolved in water, the better ability to transfer electrons will be obtained. Conversely, the higher conductivity means the more chemicals in solution. In AFACs, the conductivity can reflect the salt dissolved into water, while the more solutes is contained, the higher conductivity will be. In this study, to understand the pattern of salt released into water, conductivity test was operated, where the conductivities of chemical (sodium chloride) were measured by meter-probe (DDS-11A, made by Ridao Scientific Instrument Co., LTD in Shanghai, China), with a Platinum black electrode parameter (electrode constant = 0.993). During the experiments, the conductivities of solutions were measured fairly at different temperatures with temperature compensation. The application method of conductivity meter can be referred to the literatures [12,20,21].

As described above, the anti-freeze filler has been modified with moisture repellents. Fig. 2 shows the hydrophobicity of anti-freeze filler (1 g per 500 ml deionized water). It is obviously that ICB-3 obtained the best hydrophobicity, and ICB-1 is the most hydrophobic. Further study indicates that the hydrophobicity is affected by particle size, the smaller the better.

In addition, the conductivities of AFAC are also measured with this method, in which Marshall pieces or incompact mixtures were put into 2500 ml deionized water in glass beakers, as shown in Fig. 3. Before infiltrated in water, specimens were deposited in stainless steel baskets, and then entered into water together. When testing the solution conductivity, the baskets must be lift up and down to make the solute symmetrical. Concerning the evaporation, the glass beakers were sealed by preservative film.

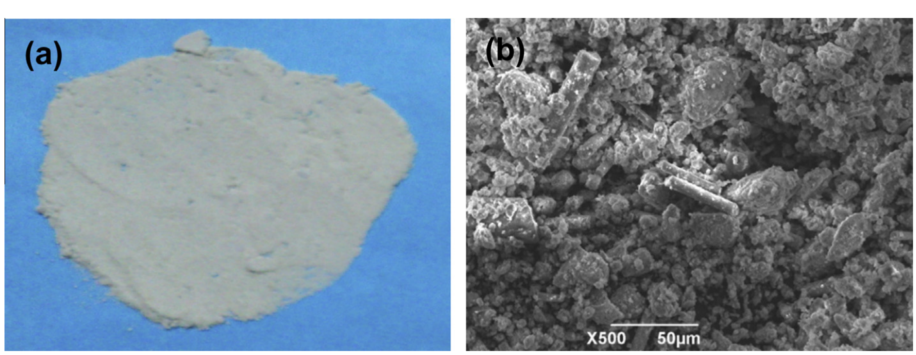

Fig. 1. Morphology of anti-freeze filler (IceBane^{TM}).