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Preparation and anti-icing properties of a superhydrophobic silicone coating on asphalt mixture

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HIGHLIGHTS

- The contacting angle of RTV/LDHs coating is 152.3°.
- RTV/LDHs coating delays the freezing process of surface water droplet.
- RTV/LDHs coating reduces the surface ice detachment force.
- Hydrophobic and anti-icing properties of RTV/LDHs coating are durable.

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ABSTRACT

The formation of ice on pavement is a serious issue for driving safety. This paper proposes a new method of preparing a superhydrophobic silicone coating on asphalt pavement surfaces for the anti-icing purpose. The object of this paper is to investigate the anti-icing properties of the superhydrophobic silicone coating through the freezing time of water droplets and detachment forces of ice on asphalt mixture surfaces. In the preparation process of the coatings, an additive (layered double hydroxides, or LDHs) was initially modified by γ-methacryloxypropyltrimethoxysilane (KH550). Fourier transform infrared spectra and X-ray diffraction patterns were used to prove that LDHs particles have been successfully grafted by KH550. A special rubber (No. 107 room temperature vulcanized silicone rubber, or RTV) was then mixed with the modified LDHs to obtain the compound coating. Different amounts of solvents (No. 120 solvent naphtha) were sprayed on the compound coating to produce the micro/nano-scale rough surface. Contact angle test results show that the maximum contact angle of RTV and modified LDHs compound (RTV/LDHs) coating is 152.3° when 100 g/m^2 of No. 120 solvent naphtha was sprayed on this coating. The freezing time of water droplet on the asphalt mixture with RTV/LDHs coating is 3 times longer than that on the asphalt mixture without coating. The ice detachment force on the asphalt mixture with RTV/LDHs coating decreases by 71% of that on the asphalt mixture without coatings. The vehicle traveling test displays that the RTV/LDHs coating has durable hydrophobic and anti-icing properties after the tire friction. From the above results, it can be concluded that this new superhydrophobic silicone coating makes significant improvements on the anti-icing properties of asphalt pavement.

1. Introduction

Asphalt mixture has been widely used in highway pavement due to its advantages of low noise level, easy maintenance and driving comfort. A common problem with asphalt pavement is the formation of ice when air temperatures are below the freezing temperature of water. The conventional method is to spread salt on

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the pavement or remove ice mechanically. However, the main component of spreading salt is sodium chloride, which has a corrosive effect on vehicles and causes environmental problems [1–5]. Mechanical ice-removing methods are not cost-effective due to their enormous requirements of time and manpower. In recent years, some new ice melting methods have attracted great attention from many researchers. One of the methods is to embed electrical cables in asphalt mixture to melt ice automatically, but it has to consume a large amount of electricity [6]. Another one is to mix chemical chloride-based agents into the asphalt mixture, but traffic load can cause chloride solvent to be gradually released [7–9], which results in the same problems caused by spraying salts [10] and weakens the rheological properties of asphalt binder [11,12]. The above methods both focus on ice melting solutions, but there is still a lack of literature in regards to facilitating ice removal or delaying ice formation on the asphalt mixture.

Superhydrophobic surfaces, such as lotus leaves and butterfly wings in nature have been investigated by many researchers [13,14]. These surfaces have a common feature that their contact angles with water are more than 150° [15]. The anti-icing properties of various superhydrophobic coatings have become hot topics in many fields. Cao et al. [16] prepared a superhydrophobic coating consisting of acrylic polymer resin, silicone resin and nanoparticles. They found that this coating can effectively delay the ice formation and the anti-icing property is relative with the nanoparticle size. Antonini et al. [17] sprayed Teflon on etched aluminum to avoid icing aeronautic wind and proved that this superhydrophobic coating can reduce surface energy by up to 80%. Wang et al. [18] fabricated a superhydrophobic coating on aluminum substrates. They showed that the water droplet rolled off on this coating with a tilt angle of 30° even under the environmental conditions of −10 °C and 85–90% humidity. Zheng et al. [19] immersed anodized aluminum plates into the molten myristic acid to obtain a superhydrophobic coating and they found that the ice adhesion strength of this coating is 0.065 ± 0.022 MPa which is much lower than that of aluminum surface (1.024 ± 0.283 MPa). In view of these papers, superhydrophobic surfaces have potential to offer superior anti-icing properties in various fields.

To prepare superhydrophobic coatings, researchers usually use the sol-gel method [20], the etching method [21], the isoelectric precipitation [22], the phase separation method [23] and self-assembly method [24]. However, high resource cost and complex preparation process greatly restrict the large scale application in asphalt pavement. Room temperature vulcanized silicone rubber (RTV) with low surface energy has good stability, corrosion resistance and excellent processability at a wide range of temperatures. Xu et al. [25] investigated the anti-icing performance of RTV coating containing sufficient carbon black on porcelain insulators and found that ice formation on insulators can be reduced significantly. Arianpour et al. [26] used spin-coating hexane-diluted supensions method to prepare RTV coatings on aluminum surfaces. The carbon-black, titaia or ceria nanopowders were sprayed on RTV surface to improve the surface roughness. The result showed that surface modified RTV can obviously delay the freezing time of water droplets. Though some practical applications have focused on the anti-icing property of superhydrophobic coatings, little research about the preparation and anti-icing property of superhydrophobic coatings on asphalt pavement has been reported.

In this work, RTV and hydrophobic LDHs were used to prepare superhydrophobic coatings on the asphalt surface. First, LDHs particle surfaces were modified by γ-methacryloxypropyltrimethoxysi lane (KH550). Then, the modified LDHs were mixed with the RTV compound and they were sprayed on the substrate (asphalt binder or asphalt mixture). Finally, No. 120 solvent naphtha was sprayed on the RTV and LDHs (RTV/LDHs) coating surface until the solvent was thoroughly evaporated. The hydrophobic property of the asphalt binder and asphalt binder coatings was evaluated by the water contact angle test. The anti-icing performance of asphalt mixtures were measured by a freezing test and ice detachment test.

2. Experimental

2.1. Materials

Polydimethylsiloxane (No. 107 RTV) is a commercial product (industrial grade) and its viscosity is 5000 mPa.s. The average particle size Magnesium–Aluminum layered double hydroxides (Mg–Al LDHs) is 100 nm and its surface area is 55 m^2/g. γ-methacrylox ypropyltrimethoxysilane (KH550, analytically pure) was used to modify LDHs surface. Tetraethyl orthosilicate and dibutyltin dilaurate (industrial grade) were selected as cross-linking agents for RTV. No. 120 solvent naphtha (industrial grade) were used to solve the surface RTV. Penetration of asphalt binder is 68 dmm at 25 °C. Aggregates of the asphalt mixture were basalt and mineral powder (machine-glazed limestone).

2.2. Preparation of superhydrophobic coatings

50 g of LDHs powder and 25 mL of anhydrous ethanol were mixed in a flask with three necks. Then 1.5 g of KH550, 45 mL of ethanol and 5 mL of deionized water were added into the above flask at 60 °C and vigorously stirred for 30 min. During this stirring process, the acetic acid was added dropwise to maintain the pH of the mixture at around 3.5. Subsequently, the white resultant slurry was filtered, thoroughly washed three times using deionized water and dried at 105 °C for 6 h. Finally, the dried solid was milled to pass through 200 mesh net to obtain the modified LDHs particles.

RTV, tetraethyl orthosilicate, dibutyltin dilaurate, n-hexane and modified LDHs at the mass ratio of 100:5:1:10:20 were stirred for 10 min. The resultant RTV/LDHs compounds were sprayed using an electric spray gun with a gas pump on the substrates (asphalt bind or asphalt mixture). After curing, No. 120 solvent naphtha was sprayed on the coating surface. The spraying amounts were 60 g/m^2, 80 g/m^2, 100 g/m^2, 120 g/m^2 and 140 g/m^2, respectively. When the No. 120 solvent naphtha on the coating surface was completely volatilized, the RTV/LDHs coatings with micro/nano-scale coarse structures were obtained. An asphalt binder, and an asphalt binder covered with RTV coatings, were painted on a glass slide for the contact test. The schematic preparation process of RTV/LDHs coatings is shown in Fig. 1.

2.3. Preparation of asphalt mixtures

According to the standard JTG F40-200 for Chinese construction of highway asphalt pavements, the gradation of asphalt mixture was AC-16 type and the gradation curve is described in Fig. 2. The optimum asphalt binder content is 4.6 wt%, which is determined by Marshall tests. RTV and RTV/LDHs compound were separately sprayed on the surfaces of Marshall specimens. Then No.120 solvent naphtha was sprayed on the RTV/LDHs compound surface following the steps in Section 2.2.

2.4. Characterizations

In this work, FTIR spectrometer (Nexus, Thermo Nicolet Corp., U.S.) was used to record the spectra of the pristine LDHs and the modified LDHs. X-ray diffraction (XRD) patterns of pristine LDHs and the modified LDHs were recorded by a D8 Advance Diffractometer (Bruker Corporation, Germany). The radiation wavelength