Application of Anti-icing Hydrophobic Electric Heating Film in Urban Bridge Management

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Abstract. The ice accumulation on bridge cables in extreme cold climate threatens the safety of the bridge and the passing people or vehicles. This article aims to introduce a technology for using a hydrophobic electric heating film to prevent ice accumulation and its application method on cable sheaths of cable-stayed bridges. The combination of electric deicing and hydrophobic coating is proposed to avoid the defects of high energy consumption and poor deicing effect of hydrophobic coating. In addition, artificial icing tests were carried out on bridge cable sheath samples with different surface. By analyzing the results of icing tests, obtained the anti-icing mechanism of hydrophobic electric heating film. This technology could effectively prevent ice formation, speeds up ice removal, and offers significant advantages in anti-icing applications. Based on experimental results, the application of hydrophobic electric heating film on bridge could significantly reduce the threat of icing disaster to urban traffic safety.

Keywords: cable-stayed bridges, anti-icing technology, urban traffic management, icing disaster prevention

1 Introduction

Bridge cables play a crucial role in supporting the main load of a bridge. The service life and efficiency of bridge are directly impacted by the safety and durability of bridge cables. The bridge cable sheath, a protective layer wrapped around the cable's outer surface, prevents corrosion and damage from the external environment, enhancing cable durability and safety[1]. However, these sheaths are vulnerable to erosion by ice, snow, and precipitation in cold climates, which can lead to ice accumulation, increased weight, wind resistance, reduced strength, and even cable damage[2].

Common de-icing methods, like thermal and mechanical approaches, consume significant amount of energy and is harmful to the environment. Thermal de-icing employed on bridges can result in localized temperature changes, leading to thermal stress on the concrete surface and an increased risk of cracking, while also consuming a significant amount of energy and incurring high costs[3]. Mechanical de-icing applied to

Z. Ahmad et al. (eds.), *Proceedings of the 2024 5th International Conference on Urban Construction and Management Engineering (ICUCME 2024)*, Advances in Engineering Research 242,
https://doi.org/10.2991/978-94-6463-516-4_17

bridge cables may result in scraping and abrasion, causing damage to their surface protective layer, increasing maintenance costs, and reducing lifespan. Additionally, improper operation may lead to cable deformation or rupture, further impacting the safety and stability of the bridge[4]. Hydrophobic coatings, such as fluoroplastics and silicone rubber, reduce ice adhesion but work best in wet snow conditions and cannot prevent supercooled water from freezing. Existing anti-icing technologies face limitations like high energy consumption, inefficiency, environmental concerns, inconvenience, and cost. Ongoing innovation and optimization are crucial for enhancing anti-icing performance and reliability[5].

This paper introduces an innovative de-icing system for bridge cable sheaths. It combines electric heating with hydrophobic coating to address energy consumption and low effectiveness issues. The de-icing system aims to meet urgent engineering needs for anti-icing in outdoor facilities, including transportation bridges. Additionally, the study proposes an icing test method and evaluates anti-icing performance based on high-density polyethylene (HDPE) material. This surface characteristic of the superhydrophobic electric heating film was analyzed, which can provide theoretical support for efficient anti-icing solutions across various scenarios and icing conditions. This article provides a non-destructive, low energy consumption, environmentally friendly, and efficient structural anti-icing technology solution, which has the potential to truly solve urban building anti icing problems.

2 Hydrophobic Electric Thermal Anti-Icing/De-Icing Device for Bridge Cable Sheath

To prevent bridge cable from icing in cold weather, we designed a hydrophobic electric thermal anti-icing system for cable sheaths, the illustration was shown in Fig. 1. The anti-icing system was composed of a three-layer structure. The base layer was made of polymeric materials used as the cable sheaths, like high-density polyethylene (HDPE), polyvinyl chloride (PVC), polyurethane (PU), rubber, et al. The second layer, named electric heating layer was applied to the outer surface of the base layer, adhering closely to the bridge cable. The third layer, which is the hydrophobic layer in the upside, covered the electric heating layer. The power supply was connected to the electric heating layer, providing electricity for de-icing purposes.

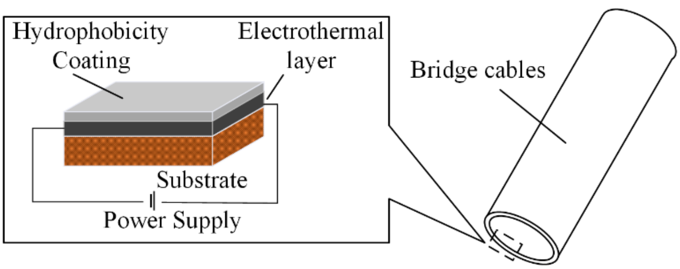

Fig. 1. Illustration of the structure of the hydrophobic electric thermal anti-icing system for cable sheaths

To ensure consistent and uniform heating across the electric heating area and avoid variations in heating power density caused by uneven resistance distribution, a spacing arrangement between the conductive channel and the heating area of the electric heating layer was developed. The heating and heat transfer layer utilized flexible conductive thermal materials like carbon fiber and conductive polymer. Additionally, parallel striped copper foil or copper wire with spacing was pressed on top to serve as the conductive channel (as shown in Fig. 2). Bridge cable sheaths with double helix structures resistant to wind and rain can have conductive copper wires arranged on both sides of the helix. For sheaths lacking spiral structures, parallel copper foils are arranged within the conductive layer to serve as conductive channels.

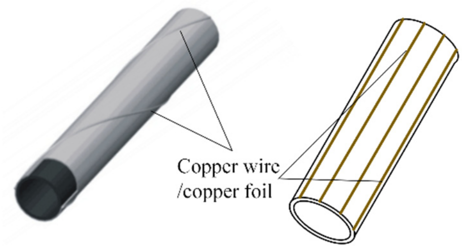

Fig. 2. Design diagram of hydrophobic electric heating film for bridge cable sheath

In practical applications, the hydrophobic electric thermal anti-icing system for bridge cable sheaths can incorporate online monitoring modules for meteorological data and surface conditions. This allows real-time access to climate information and bridge cable surface temperature for integrated control of electric heating power. By regulating heating and cooling, it prevents water vapor condensation and ice crystal formation on the surface of objects, enhancing the anti-icing capability of bridge cables, as shown in Fig. 3.

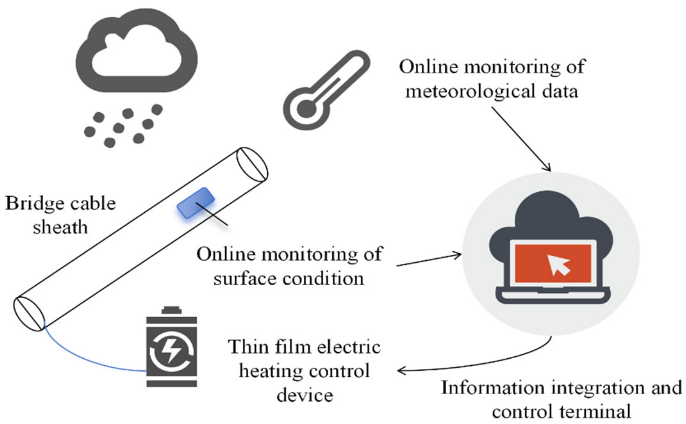

Fig. 3. Application diagram of anti-icing (de-icing) device for hydrophobic electric thermal bridge cable sheath

3 Artificial Icing Test Method and Platform

This paper adopts an artificial icing test method to test the anti-icing performance of cable-stayed bridges in the event of cable icing. The main equipment used in the artificial icing experiment is a high and low temperature test chamber, and the layout of the test device is shown in Fig. 4. The test frame is designed to match the length and radius of the HDPE protective sleeve. The sample is installed and secured on the main crossbeam structure at an adjustable angle. The icing characteristics of bridge cables are similar to those of power grid transmission lines. Therefore, the experimental plan refers to the Chinese power industry standard "DLT1247-2013 High Voltage DC Insulator Ice Flashover Test Method" and simulates the conditions of rime icing in natural environments by spraying supercooled water at low temperature[6]. The indoor temperature is set to -5~-4 °C, with super-cooled droplets averaging about 80 μm in size. Spray flow is controlled between 80~100 L/h. Throughout the icing process, the indoor fan in the climate room intermittently operates, producing circulating air ranging from 1 to 12m/s.

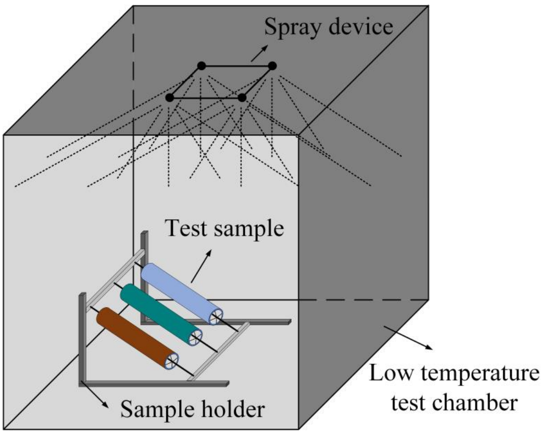

Fig. 4. Schematic diagram of artificial icing test device

4 Anti-icing Performance of Hydrophobic Electric Thermal Film

The widely used bridge cable sheath was selected as the carrier for experimental verification of this technology. A comparative test was carried out on the samples using the artificial icing test of the bridge cable sheath mentioned earlier. The test involved untreated samples, samples with superhydrophobic coatings, and samples coated with hydrophobic electric heating films. Specifically, the bridge cable sheath coated with hydrophobic electric heating films had both untreated section and section with pure electric heating surfaces to compare the anti-icing effect. The artificial icing test results are shown in Fig. 5.

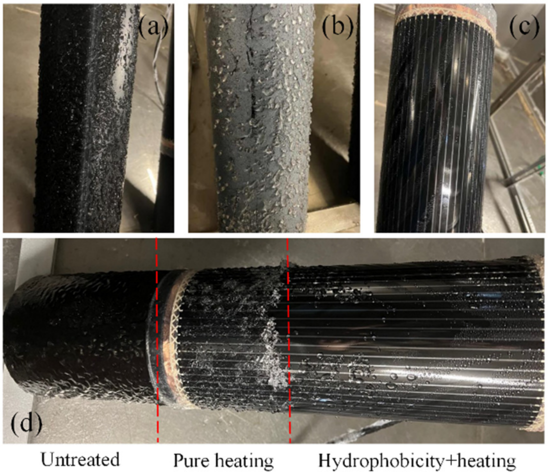

Fig. 5. Schematic diagram of artificial icing test results. (a) untreated sample, (b) superhydrophobic coating, (c) hydrophobic electric heating film, (d) Comparison of icing characteristics.

According to Fig. 5 (a)~(c), under identical icing conditions and exposure time, the untreated bridge cable sheath shows dense and uniform icing on its surface. While the sample with superhydrophobic coating shows sparse ice block distribution, and the sample with hydrophobic electric heating film remains completely free of icing.

According to Figure 5 (d), at the same electric heating power density, the electric heating film without a hydrophobic coating is fully covered by a loose ice layer. In contrast, the surface of the electric heating film with a hydrophobic coating only has sparse liquid droplets. Setting the surface heating temperature to 0 °C completely prevented the surface water droplets from freezing and forming ice, demonstrating a significant anti-icing effect.

Drawing from experimental results and theoretical analysis, the impact of hydrophobic materials on surface water droplet freezing can be summarized with the following formula[7].

$$I = P \cdot R \cdot J \tag{1}$$

where, I is the amount of water droplets that have completely frozen on the surface.

P is the flow rate of supercooled droplets falling on the surface.

R is the proportion of water droplets that remain on the surface in the falling droplets on the surface.

J is the proportion of water droplets that can ultimately be converted into completely frozen water droplets in the droplets remain on the surface.

Hydrophobic coating is primarily attained by minimizing parameters P and R to inhibit the freezing of supercooled water droplets on the surface, preventing icing formation[7]. Usually, achieving superhydrophobicity on the surface is necessary to markedly diminish initial surface icing formation. In this study, incorporating an electric heating layer significantly decreased the likelihood of water droplets on the surface completely freezing. When combined with hydrophobic coatings, it resulted in a notable anti-icing effect.

5 Conclusions

This article aims to develop and test a hydrophobic electric heating film anti-icing technology for cable sheaths of cable-stayed bridges that take the advantages of hydrophobic anti-icing technology and electric heating de-icing technology. The experimental results indicate that, hydrophobic coatings cannot effectively prevent the formation of ice on the surface of bridge cable sheaths. At low heating power density, icing can also form on the surface of the electrically heated film. Anti-icing hydrophobic electric heating film can effectively prevent ice formation on bridge cable surfaces and speeds up ice removal. It offers both energy efficiency and safety, presenting significant advantages in bridge cable sheath anti-icing applications.

Based on our research findings, the hydrophobic electric heating anti-icing device has the following characteristics: simple technical principle, low manufacturing cost, low energy consumption, and significant anti-icing effect. It is not only suitable for the application of bridge cable jacket anti-icing, but also has great potential for expansion to other urban buildings. This technology has great potential for development and broad prospects for application.

Acknowledgment

Funded by Guangdong Basic and Applied Basic Research Foundation (2023A1515012899).

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