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Robust anti-icing coatings via enhanced superhydrophobicity on fiberglass cloth

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A B S T R A C T

Robust superhydrophobic coatings with anti-icing properties were obtained by a simple approach, i.e., immersing and spraying of adhesive/hydrophobic silica dispersion on fiberglass cloth. Scanning electron microscopy, water contact angles, abrasion tests and dynamic icing tests were performed to characterize the morphology, hydrophobicity, mechanical durability and icephobicity of the coatings. The experimental results demonstrated that the coatings have good abrasion resistance. The water contact angle and the water sliding angle remain greater than 150° and lower than 10°, respectively, after 60 cycles of abrasion. Furthermore, the anti-icing properties of superhydrophobic surfaces were investigated under dynamic flow conditions. It was found that the coatings had the ability to delay ice nucleation without electrical heating, and avoid ice adhesion partly or even completely, under a given mass of heat, which was much less than that of uncoated surfaces. The fiberglass cloth based coatings could reduce by up to 51% of the heating power required to avoid ice accumulation, compared to uncoated surfaces.

1. Introduction

Ice formation on surfaces may cause increasing severe problems that will deteriorate performance of aircrafts, antennas, wind turbines, power lines and cause unpredictable losses of life and property. Over last decades, researchers have been dedicated in designing anti-icing coatings to delay ice nucleation and reduce ice accretion. Until now, a great amount of potential approaches such as superhydrophobic surfaces (Antonini et al., 2011; Mishchenko et al., 2010; Sarkar and Farzaneh, 2009; Shen et al., 2015), slippery liquid infused porous surfaces (SLIPS) (Kim et al., 2012; Liu et al., 2015; Zhang et al., 2015), anti-icing coating with an aqueous lubricating layer (Chen et al., 2014; Dou et al., 2014) and antifreeze protein grafted surfaces (Gwak et al., 2015) have been widely exploited to serve as anti-icing coatings. All of these anti-icing strategies have been demonstrated to have the abilities of reducing ice adhesion, delaying ice nucleation or repelling metastable water droplets before freezing occurs. Due to convenience and simplicity, superhydrophobic surfaces are still regarded as the most feasible methods and are frequently applied.

In recent years, the feasibility of superhydrophobic surfaces working as anti-icing coatings have been deeply researched. A large number of reports have demonstrated that superhydrophobic surfaces can delay ice nucleation and repel metastable water droplets before freezing occurs. Cao et al. (2009) prepared superhydrophobic surfaces using nanoparticle-polymer composites for anti-icing, and demonstrated that the anti-icing capability of the surfaces depended not only on their superhydrophobicity but also on the surface morphology. He et al. (2011) studied the effects of ZnO nanorod arrays superhydrophobic surfaces towards ice/frost formation, and demonstrated that superhydrophobicity to condensed micro-droplets at temperatures below the freezing point is desirable for effectively retarding ice/frost formation. Liao et al. (2015) studied the anti-icing performance in glaze ice of nanostructured superhydrophobic film prepared by RF magnetron sputtering and hexadecyltrimethoxysilane modification, and found that the nanostructured film could effectively reduce the freezing area. Although these reports demonstrate that superhydrophobic surfaces are promising candidates for anti-icing applications, most of these research just investigated the anti-icing properties of superhydrophobic surface under static conditions or at low droplets velocity. Without doubt, dynamic anti-icing performance, especially under high droplets velocity conditions, is a practical challenge to the anti-icing coatings.

In practical applications, anti-icing coatings often encounter extreme environment like high wind, sand storm, freezing rain, etc. A superhydrophobic surface must enhance its mechanical durability before working as a practical anti-icing coating. Recent research proposed several approaches to improve the mechanical durability of the superhydrophobic coatings such as adhesives (Lu et al., 2015) and textured surfaces (Jiang et al., 2014; Yokoi et al., 2015). However, dynamic anti-icing tests have hardly been conducted for those coatings.

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In this work, the fiberglass cloth-based anti-icing coatings with superior durability are firstly introduced. In our work, fiberglass cloth and pressure-sensitive adhesive are combined and applied to improve the durability of the coatings. Comparative experiments are carried out to confirm their superior mechanical durability and anti-icing performance especially under the high droplets velocity conditions. These results will be helpful to provide insights into the role of superhydrophobicity and mechanical durability towards dynamic anti-icing performance, and therefore, helpful for practical applications of anti-icing coatings.

2. Material and methods

2.1. Materials

Aluminum (A1060) plates, 34 mm × 34 mm in size, were used as substrates. Plain weave fiberglass cloth was commercially available, and the diameter of the original filament is about 5 ± 0.5 μm, 50 ± 5 filaments in one tow, and the center distance between the tows is about 400 μm. (George et al., 2016) Pressure-sensitive adhesive was obtained from 3 M Company. The hydrophobic SiO_2 nanoparticles were obtained from Wacker Chemie AG. 1H,1H,2H,2H-Perfluorodecyltriethoxysilane (FAS-17) was obtained from SICONG chemical. Ethanol (Analytical reagent) and acetone (Analytical reagent) was purchased from Beijing Chemical Works.

2.2. Fabrication of robust superhydrophobic coatings FC and AA

Two kinds of superhydrophobic coatings, i.e., with fiberglass cloth (named FC, the acronym of fiberglass cloth) and without fiberglass cloth (named AA, the acronym of aluminum/adhesive), were prepared to investigate the durability. The procedure of fabricating superhydrophobic surfaces are illustrated as shown in Fig.1.

2.2.1. Preparation of silica dispersion for spraying

A certain amount of hydrophobic fumed silica was added into acetone and the dispersion was dispersed for 30 min in an ultrasonic cleaner.

2.2.2. Preparation of adhesive-silica dispersion for immersing

Pressure-sensitive adhesive and hydrophobic fumed silica were added into acetone. The weight ratios of adhesive and silica to acetone were 0.03 and 0.012, respectively. And then the dispersion was dispersed for 10 min in an ultrasonic cleaner.

2.2.3. Preparation of the fiberglass cloth based superhydrophobic coatings FC

Fiberglass cloth was immersed into adhesive-silica dispersion for 2 min, spread out and entirely dried at room temperature. Subsequently, a thin layer of about 100 μm of pressure-sensitive adhesive was sprayed on the aluminum substrates, and then the treated fiberglass cloth was spread out and adhered to the substrates. Finally, the superhydrophobic coating FC was obtained by spraying a thin layer of silica dispersion onto the fiberglass cloth and FAS-17 was used to modify the possibly exposed part of the fiberglass and adhesives (Ganesh et al., 2013; Yokoi et al., 2015).

2.2.4. Preparation of the aluminum/adhesive based superhydrophobic coatings AA

To recognize the effect of fiberglass cloth, aluminum/adhesive based superhydrophobic coatings AA were fabricated with adhesive and silica dispersion, but without fiberglass cloth. After the pressure-sensitive adhesive spraying step, the aluminum substrates were immersed into adhesive-silica dispersion for 2 min. Then the aluminum/adhesive based superhydrophobic coating AA was obtained by spraying a thin layer of silica dispersion onto the substrates, and FAS-17 was used to modify the possibly exposed part of the fiberglass and adhesives.

The main difference between these two coatings is the fiberglass cloth which provided the regular micron-sized texture.

2.3. Characterization of robust superhydrophobic coatings FC and AA

The water contact angles (WCA) and water sliding angles (WSA) were measured using 5 μL deionized water droplet on a SL200B Static and Dynamic Optical Contact Angle Goniometer (Shanghai SOLON Information Technology Co., Ltd.). The morphology of the coatings was examined using a scanning electron microscopy (SEM, JCM 6010). Sandpaper abrasion tests were carried out to measure the mechanical durability of the coatings. The anti-icing properties of the coating FC were investigated under dynamic flow conditions using a custom-made low-temperature testing device.

3. Results and discussion

3.1. Morphology of the coatings

Superhydrophobic performance is dependent upon enough surface roughness and low surface energy (Cassie and Baxter, 1944; Wenzel, 1936). Apart from low surface energy of hydrophobic SiO_2 nanoparticles, controlling morphology of coating surface is also necessary for superhydrophobic performance.

The SEM images of the sample surfaces are presented in Fig.2. Fig.2a shows the morphology of fiberglass cloth after immersed in adhesive-

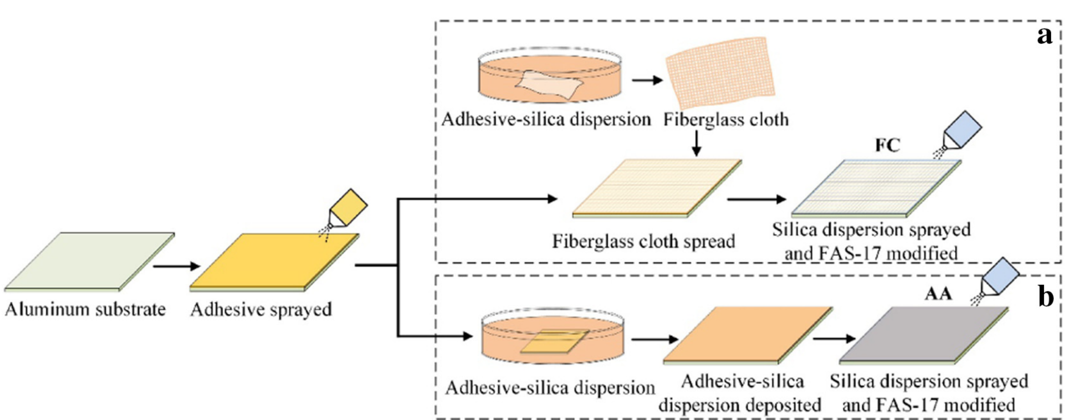

Fig. 1. Schematic of the fabrication of superhydrophobic coatings (a) FC and (b) AA.