Oil-Infused Slippery Surface on Al Substrates Fabricated by Chemical Etching

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Abstract. In recent years, the oil-infused slippery surfaces inspired by Nepenthes pitcher have potential applications in domestic and industrial fields due to their excellent water repellence. However, the current preparation methods of the oil-infused slippery surfaces have the disadvantages of time-consuming, expensive equipment and complex processes. In our research, we reported an approach to prepare the oil-infused slippery surface with multi-functional applications by simple chemical etching. First, Al plates were etched by hydrochloric acid solution and modification with lower surface energy. Then, the as-prepared samples were immersed into the lubricant oil. After that, the oil-infused slippery surface with a water slide-off angle of 3° was obtained. The freezing rain tests, chemical stability tests, and self-cleaning tests were conducted on original Al plate and the as-prepared sample. This work will enrich the preparation methods of the oil-infused slippery surfaces.

1. Introduction

Inspired by Nepenthes pitcher, oil-infused slippery surfaces, which can repel water liquids at a low slide-off angle have attracted researcher’s extensive attention due to their potential applications prospects in anti-icing [1], antifouling properties [2], corrosion resistance [3] and droplet manipulation [4]. To date, various oil-infused slippery surfaces have been prepared by infusing lubricant oil into superhydrophobic surfaces with micro/nano structures. Liu et al. [5] reported a slippery liquid-infused porous network surfaces by electrochemical etching processes, hydrothermal process and lubricant infusion process, showing excellent anti-icing/deicing performance. Sun et al. [6] fabricated a slippery liquid-infused porous surface on Al substrates by electrochemical etching, anodic oxidation and lubricant infusion which have a bright future in harsh environments. Jin and co-authors [7] fabricated a silicone oil swelling slippery liquid-infused porous surfaces by swelling silicone oil into magnetic matrix, demonstrating excellent self-healing ability. However, the aforementioned oil-infused slippery surfaces prepared by these methods have the disadvantages of time-consuming, expensive equipment and complex processes, which have limited application environments. Thus, it is important to develop a facile, low-cost, and efficient approach to prepare oil-infused slippery surface that can be used in different harsh environments.

In this paper, we reported a simple method to prepare oil-infused slippery surface on Al substrates by chemical etching, modification of lower surface energy and immersing in silicone oil. The as-prepared oil-infused slippery surface exhibited good anti-icing performance, excellent acid and base...
resistance, and outstanding pollutant-resistance. We believe that our design and strategy could aid the development of the oil-infused slippery surfaces in our daily life.

2. Experiment Section

2.1. Materials
Analytical-grade hydrochloric acid was purchased from Tianjin Kemi Chemical Reagent Co., Ltd. Flouroalkylsilane \([FAS, C_8F_{13}H_4Si(OCH_2CH_3)_3]\) was purchased from Degussa Co., Ltd (Germany). Ethyl alcohol was purchased from Fuyu Fine Chemical Co., Ltd (China). Deionized water was obtained from the key laboratory of ministry of education.

2.2. Preparation of the oil-infused slippery surface on Al substrates
The preparation processes of the oil-infused slippery surface on Al substrates are shown in figure 1. Prior to chemical etching, Al plates (purity > 99.9%, Shengjili Co., Ltd, Shenzhen) were polished by 800# and 1500# sandpaper and ultrasonically cleaned in ethanol to remove the oxide layer and greasy dirt, and then dried in an oven at 60°C. Then, the polished Al plates were immersed in the hydrochloric acid solution (3 M) for about 30 min. After that, the samples were immersed in the 1 wt% ethanol solution of FAS for 20 min and dried to endow the Al plates superhydrophobicity. Next, the oil-infused slippery surface was prepared by immersing the superhydrophobic Al surfaces in silicone oil (viscosity ~ 10 cst, Dow Corning Co. Ltd, USA) for 3 h.

![Figure 1. Schematic diagram of the preparation processes of the oil-infused slippery surface on Al substrates.](image)

2.3. Characterizations
The contact angle and roll-off angle were measured by optical contact angle meter (DSA100, Krüss, Germany) at ambient temperature. The digital images of the samples were recorded by camera (Alpha 7CL, Sony Co. Ltd, Japan). Anti-icing tests were conducted by putting the original Al plate and oil-infused slippery surface into an environmental chamber with temperature of -8 °C. The inclination angle of the samples was 20°. The artificial raindrop with temperature of 2 °C was dropped onto the samples with the impact velocity of 1 m/s. The rainfall was 700 μL/min. Chemical stability tests was conducted by dropping the acid (pH = 0) and base (pH = 14) aqueous solution onto a 20° inclination angle samples.

3. Results and Discussions
Figure 2 shows the digital images of the oil-infused slippery surface. The water droplets on the samples showed hemi-spherical. The contact angle of a 50 μL water droplet on the oil-infused slippery surface was about 101° and the slip angle was 3°, as shown in figure 2(c).
Anti-icing performance is an important indicator of the oil-infused slippery surface. We then conducted the anti-icing tests of the oil-infused slippery surface. Firstly, two Al plates with 20° inclination angle were placed at an environment chamber with a temperature of -8°C. One was original Al plate, and another was oil-infused slippery surface on Al substrates. Then, water droplet with a temperature of 2°C were dropped onto the samples with a rainfall of 700 μL/min, as shown in figure 3(a). For the ordinary Al plate, water droplet easily adhered on the surface and then frozen into ice. In addition, the ice mass on the ordinary Al plate increased linearly with the raining time. It can be seen from figure 3(b) that approximately 4.9 g ice formed on the ordinary Al plate. By contrast, water droplet can easily slide from the oil-infused slippery surface and there was no ice on the coating. The tests results indicated that the as-prepared oil-infused slippery surface by our method possessed excellent anti-icing performance, shown in figure 3(c).

We then performed the self-cleaning tests of the oil-infused slippery surface. Firstly, the samples were contaminated by 1 g chalk powder. It can be seen from figure 4 that 2 μL water droplets can took away the powder on the oil-infused slippery surface. Compared with the original Al plate, there was no residue left on the oil-infused slippery surface. The results demonstrated that the oil-infused slippery surface fabricated by our method shows excellent self-cleaning property which can be used in complex environment.
Figure 4. Self-cleaning tests of the oil-infused slippery surface compared with the original Al substrates.

In order to explore whether the oil-infused slippery surface can endure the hot water, polluted, acid and base environment, chemical stability tests were conducted. Here, coffee droplets, hot water, acid (pH = 0) and base (pH = 14) aqueous solutions were dropped onto the oil-infused slippery surface to test the chemical stability. It can be seen that these four droplets could roll off easily from the samples. The average velocity for hot water, acid droplet, and base droplet was 4.2 mm/s, 4.5 mm/s, and 4.6 mm/s, respectively. Meanwhile, the average velocity for coffee droplet was 2.1 mm/s. This is because the kinematic viscosity of coffee was lower, which resulted in a lower average velocity, as shown in figure 5. The slippery property of the oil-infused slippery surface did not change significantly, indicating that the as-prepared oil-infused slippery surface was chemically stable to hot water, acid and base droplets.
4. Conclusion
In our work, we reported an oil-infused slippery surface on Al substrates via simple chemical etching, modification of lower surface energy and immersing into silicone oil. The as-prepared oil-infused slippery surface showed excellent slippery properties to water. Water droplet can easily slide off the oil-infused slippery surface at a lower inclination angle for about 3°. In addition, compared with original Al plate, the oil-infused slippery surface prepared by our method has excellent anti-icing performance, chemical stability, and self-cleaning capability, which is expected to be applied in different environments.

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