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A waterproofing textile with robust superhydrophobicity in either air or oil surroundings

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ABSTRACT

Manmade superhydrophobic textiles are mechanically weak, and the current methods to solve this problem are usually laborious and cost ineffective. Herein, to address this challenge, we created a robust superhydrophobic textile by a one step immersion process that benefited of simplicity and cost efficiency. The resulting textile remained its superhydrophobicity after finger pressing, knife scratching, twisting by hands, and even 10 cycles of abrasion with sandpaper. We also studied the wetting behavior of the resulting superhydrophobic textile when exposed to oily environments. The results showed that the obtained textile still displayed superhydrophobic when immersed in oil surrounding, and it kept its water repellency even after being contaminated by oil. Moreover, exploiting its superhydrophobicity and superoleophilicity, the obtained textile was demonstrated as the separation membrane and oil absorption to separate oil from oil–water mixtures efficiently.

1. Introduction

Surfaces that display contact angles greater than 150° along with a low contact angle hysteresis for water droplets are known as superhydrophobic surfaces. On such superhydrophobic surfaces, water droplets bead up and roll off readily, removing dirt particles in their path [1–3]. In view of the significant potential of such surfaces for numerous scientific and industrial applications, many strategies have been developed to create superhydrophobic surfaces till now [4–10]. Among them, the waterproofing of textiles is considered to be among the primary potential applications for the superhydrophobic effect. Textiles with superhydrophobic property would prevent the textiles being wetted even upon full immersion in water, and thus they could find wide applications as water resistant apparel, self-cleaning textiles, and stain-free clothing [11–13]. However, one big drawback of these manmade superhydrophobic textiles is that they will lose their self-cleaning property readily when exposed to physical forces such as abrasion and twisting. Such critical weakness of superhydrophobic textiles severely hindered their practical utility [14,15]. To solve this problem, different strategies including γ-ray induced graft polymerization [16], *in situ* growth of silicone nanofilament coating [17,18], the grafting of polyacrylic acid [19], and the direct incorporation of fluorinated compound [20,21] have been proposed recently to improve the mechanical robustness of superhydrophobic textiles. However, some of the above techniques like γ-ray induced graft polymerization are either time-consuming or laborious [16], while others require special materials such as fluoro compounds, which are expensive and environmental unfriendly [20,21]. Thus, additional research is needed to explore a facile, economical, and green strategy for producing of durable superhydrophobic textiles.

Besides mechanical durability, the wetting behavior of the superhydrophobic textiles when exposed to oil should also be considered. Till now, the wetting performance of the superhydrophobic textiles in oil surroundings has not been evaluated, despite the extensive evaluation of wetting properties of superhydrophobic textiles in air. Also only few reports have shown water repellency test of the superhydrophobic textiles upon oil contaminations in air. Thus, to extend the applications of superhydrophobic textiles, characterization of these tests is necessary, and it would be highly desirable that the superhydrophobic textiles can still display water repellency and self-cleaning property when contaminated by oil and even upon immersion in oil.

In this study, we developed a facile, one step immersion approach to produce a superhydrophobic textile that possessed mechanical durability and can still function even when exposed to oil. The whole process was facile to carry out and did not require special materials. The resulting textile can keep its

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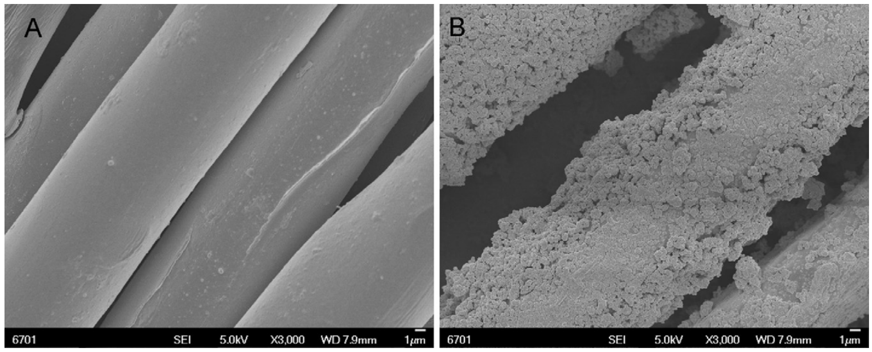

Fig. 1. FESEM images of the polyester fibers before (A) and after (B) coating with H-SiO_2–PFW.

superhydrophobic property after knife scratching, twisting by hands, finger pressing, and even 10 abrasion cycles with sandpaper. Moreover, the superhydrophobic property of the textile can be regenerated by an easy repair process when loss of superhydrophobicity occurred. The wetting behavior of the resulting superhydrophobic textile when exposed to oil was evaluated. It was found that the obtained textile still displayed superhydrophobic upon emersion in oil and kept its water repellency when fouled by oil. We also demonstrated that the superhydrophobic textile can be used as the separation membrane and oil absorption to separate oil from oil–water mixtures efficiently.

2. Experimental

2.1. Materials

SiO_2 nanoparticle (average diameter ~20 nm) was purchased from Zhoushan Nanomaterials Co., China. Octadecyltrichlorosilane was provided by Shanghai Boer Chemical Reagent Co., Ltd., China. Polyfluorowax (PFW, diameter < 15 μm) was provided by Micro Power Inc., USA. Commercially available polyester fabric was purchased from a local store and cleaned with acetone and deionized water sequentially in an ultrasonic cleaner before use. Other chemicals were analytical grade reagents and used as received.

2.2. Fabrication of hydrophobic SiO_2 particles

0.5 g SiO_2 was ultrasonically dispersed in 20 ml toluene, and 0.5 ml octadecyltrichlorosilane was added dropwise under stirring at ambient temperature. The reaction mixture was stirred at ambient temperature for 12 h. Finally, the resultant suspension was centrifugation and then placed to dry in an oven for 30 min at 80°C.

2.3. Fabrication of superhydrophobic textile

0.2 g hydrophobic SiO_2 and 0.05 g PFW were dispersed in 20 ml toluene under stirring at ambient temperature. Polyester fabric was immersed in this suspension for 1 min and then was placed to dry in an oven for 30 min at 130°C.

2.4. Characterization

Contact angle (CA) and sliding angle (SA) measurements were performed on a KRÜSS DSA 100 (KRÜSS Company, Ltd., Germany) apparatus at ambient temperature. The volume of water and oil droplet in each measurement was 5 μl. Scanning electron microscopy measurements were carried out by a JSM-6701F field-emission scanning electron microscopy (FESEM, JEOL, Japan).

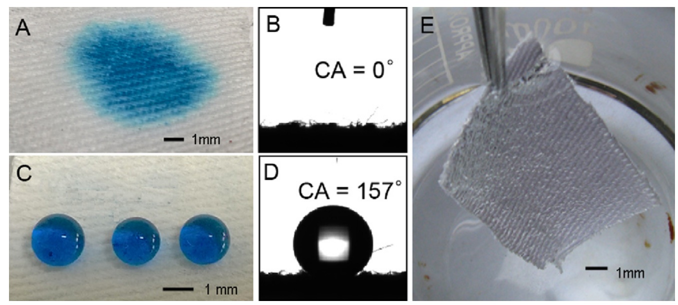

Fig. 2. (A) and (B) Water droplets can easily wet the native polyester fabric surface, displaying 0° contact angle on it; (C) and (D) water droplets with spherical shape display very high contact angles on the superhydrophobic textile. (E) A bright plastron layer is visible when the polyester fabric is submerged in water. The water was dyed with methylene blue to aid visualization.

3. Results and discussion

3.1. FESEM analysis

The polyester fabric was coated with the mixture of hydrophobic silica dioxide and polyfluorowax (hence denoted as H-SiO_2–PFW) under ambient conditions, to achieve superhydrophobic property. Fig. 1 exemplarily shows scanning electron microscopy images of the textile before and after coating. As shown in Fig. 1(A), the native polyester fabric presents a highly textured microscale fiber with a typically smooth surface. After coating, a rough H-SiO_2–PFW layer is covered on each microscale fibers, as shown in Fig. 1(B). The textile after coating generates a dual surface texture that resembles the surface morphology of a lotus leaf, and thus it provides the needed texture to enable the formation of superhydrophobic surfaces, based on the recent investigation [22].

3.2. Surface wettability of the superhydrophobic textile when exposed to air

As shown in Fig. 2(A) and (B), the native textile was wetted by water droplets readily and displayed superhydrophilic with apparent contact angle of 0° for water droplets. After coating with H-SiO_2–PFW, the textile turned to be superhydrophobic. Water droplets with spherical shape appeared to float on the coated textile surface and showed high apparent contact angle (157°) on it (see Fig. 2(C) and (D)). Moreover, water droplet can roll off the superhydrophobic textile easily at a small titling angle (5°) without leaving a trace.

When the resulting superhydrophobic textile was immersed in the water bath, a plastron (air pockets) layer that was indicative of a robust Cassie–Baxter state was formed (see Fig. 2(E)) [23]. The plastron layer was stable and remained unchanged even upon