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Mechanically durable, superhydrophobic coatings prepared by dual-layer method for anti-corrosion and self-cleaning

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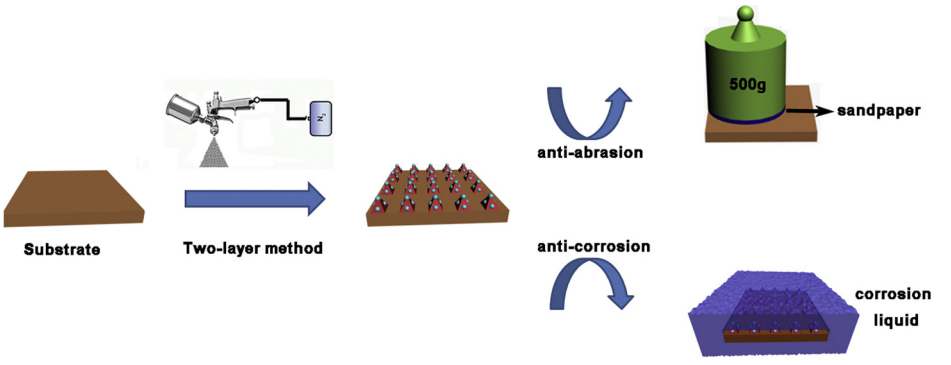
HIGHLIGHTS

- Two-layer method was used to obtain robust superhydrophobic surface.
- The coating remained stable after durable test, such as abrasion, ultrasonication.
- Anti-corrosion, anti-abrasion, and PH-resistance properties were acquired.

GRAPHICAL ABSTRACT



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ABSTRACT

Superhydrophobic materials have gathered great attention due to its great commercial potential. However, the low stability of coatings is a major challenge for applications. Here, a superhydrophobic coating with mechanical stability and corrosion resistance was obtained by using spray-coating method. We combine micro-scale roughness with low surface energy (18.5 mN m^{-1}) to create a durable hierarchical structure with critical transition pressure of 570 Pa. Interestingly, the as-prepared superhydrophobic coating exhibited good mechanical stability and corrosion resistance. Importantly, various substrates could be used for spray coating. When applied superhydrophobic coating on copper surface, corrosion resistance property was achieved. The present study provides a simple method to produce multifunctional surface.

1. Introduction

Superhydrophobic surfaces with a water contact angle greater than 150° and low water roll-off angle have attracted tremendous attention in application field such as self-cleaning [1,2], oil–water separation [3–6], anti-icing [7–9], and corrosion resistance surfaces [10,11]. There are two possible wetting regimes on rough surfaces: Wenzel state [12] and Cassie–Baxter state [13] that supports a

Abbreviations: CA, contact angle; PDMS, polydimethylsiloxane resin; PFTS, trichloro(1H,1H,2H,2H-perfluorooctyl)silane; Pc, critical transition pressure; Ra, roughness; E_{corr}, corrosion potential; *I*, corrosion density.

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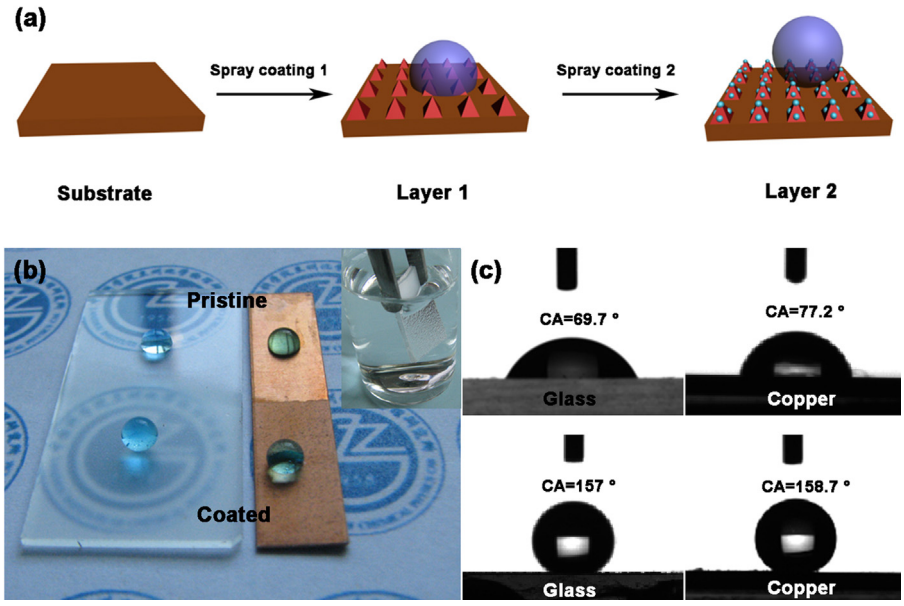

Fig. 1. (a) Schematic illustration of the fabrication of superhydrophobic coating; (b) optical images of water droplets placed on the glass and copper substrate; (c) contact angle profile of the water droplets placed on various substrates.

composite solid–liquid–air interface. In the former case, the large contact area between liquid and solid leads to high contact angle hysteresis. By contrast, water does not fill the void in between the surface roughness, resulting in an air layer underneath known as Cassie–Baxter state.

$$\cos\theta = f_1\cos\theta_1 - f_2 \quad (1)$$

where θ and θ_1 represent the contact angle of the rough surface and the flat surface, respectively. f_1 is the fraction interfacial area of solid/water on the surface, f_2 is the fractional area of air/water. Note that Cassie-to-Wenzel transition often occurs under external force, such as liquid evaporation [14], and drop impact [15,16]. The critical transition pressure Pc could be expressed as a modified equation:

$$\mathrm{Pc} = \frac{-2\gamma\cos\theta\sqrt{\pi\emptyset}}{L(1-\emptyset)} \quad (2)$$

where γ and θ are surface tension of water and advancing contact angle on the smooth surface, respectively. L is center-to-center distance between two micro-protrusions and Ø is defined as a solid fraction.

According to Eq. (1), micro- and nanometer scale roughness is expected to superhydrophobicity, since the trapped air can reduce the f_1 between a water droplet and solid surface. Therefore, the hydrophobicity of the surface is enhanced and obtained superhydrophobicity. Various strategies have been developed to fabricate micro- and nanometer scale roughness [17,18]. However, the products cannot be used in practical application because of limited mechanical stability. Therefore, it is a challenge to obtain surfaces with superhydrophobicity and mechanical durability.

One of the most promising methods is creating robust micro- and nanometer roughness structures which contain nanoparticles and adhesives. PDMS is widely used in various industrial fields due to its low surface tension [19], good thermal stability [20], and hydrophobicity [21]. A number of reports have been developed on the preparation of superhydrophobic surfaces with different inorganic nanoparticles, such as SiO_2 [22,23], CuO [24], and CNTs [25]. Unfortunately, the superhydrophobicity was only existed on the surface and shown limited durability against abrasion treatments. As a consequence, it is favorable to fabricate superhydrophobic coatings with bulk level property using a time-consuming method.

In this work, to overcome the poor durability and functionality of superhydrophobic coatings, a dual-layer strategy was used to fabricate robust superhydrophobic surface on various substrates. We have used the good forming performance of polydimethylsiloxane (PDMS) resin, and hard inorganic fluorinated alkyl silane functionalized silica nanoparticles as the material to prepare superhydrophobic coatings. It is an effective way to fabricate robust coatings by introducing nanoparticles into resin matrix. Additionally, the superhydrophobic coatings with high critical transition pressure Pc could be used as anti-corrosion barrier and the Cassie–Baxter surface is more favorable for the anticorrosion protection than the Wenzel model surface. The resulting superhydrophobic surface has the merits of self-cleaning, anti-abrasion, and anti-corrosion which is supposed to have great potential use in industrial applications.

2. Experimental

2.1. Materials

Silicon dioxide nanopowder (10–20 nm particle size), trichloro(1H,1H,2H,2H-perfluorooctyl)silane, PFTS, were obtained from Aldrich and used as received. Polydimethylsiloxane (Sylgard 184) was purchased from Dow Corning. The rest chemicals were all of analytical grade and used as received.

2.2. Sample preparation

2.2.1. Preparation of fluorinated silica

The fluorinated silica nanoparticles were prepared according to previous report [26]. Briefly, 0.5 g SiO_2 was immersed in piranha solution (H_2SO_4 and 30 wt% H_2O_2 in a 3:2 volume ratio) in 50 °C for 12 h. After put it into a drying cabinet at 60 °C for 3 h, the dried powders were dispersed in 20 ml of toluene. Then 0.5 ml PFTS was added under stirring at ambient temperature. Keep stirring for 12 h, the resultant suspension was centrifugation at 7500 r/min for 5 min. After discarding the supernatant, the final fluorinated silica was dried at 60 °C for 5 h.