A Facile Cost-effective Method for Preparing Superhydrophobic Self-cleaning Silica Nanoparticles Coating on Al Substrate

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ABSTRACT: Aluminum and its alloys have achieved extensive industrial application while contamination can cause serious problems to their aesthetic appearance and functionality. Superhydrophobic coating could be a potential solution to the problems. In this study, superhydrophobic coating on the Aluminum alloy surface was prepared via spraying hydrophobic silica nanoparticles suspension. The static water contact angle and sliding angle on the silica nanoparticle deposited aluminum alloy surface were 159±1° and 2°, respectively. In addition, the silica nanoparticle deposited aluminum alloy surface showed excellent self-cleaning property. This method may provide a facile and cost-effective route to form superhydrophobic surfaces, which would be of technological significance for many practical applications.

1 INTRODUCTION

As is well known, aluminum and its alloys have achieved extensive industrial applications due to their easy accessibility, cost efficiency, high fatigue strength, high electrical conductivity and excellent machinability. Nevertheless, aluminum and its alloys are prone to contamination in damp environment. To prevent such problems, it is needed to form a contamination resistant surface layer on Al and its alloys. This can be realized by transforming the hydrophilic nature of Al and its alloy surfaces to be superhydrophobic.

The wettability of solid surfaces is one of the most significant aspects in both industrial applications and theoretical research. As one extreme condition of wettability properties, superhydrophobic surfaces, with water contact angles greater than 150° and sliding angles less than 10°, have attracted a large amount of attention in the last two decades because it has important applications ranging from self-cleaning materials to microfluidic devices (Qing et al. 2015, Qu et al. 2007). Even on surfaces with extremely low surface energy, it is hard for water droplets to form contact angles larger than 120° on smooth and flat hydrophobic solid surfaces (Feng et al. 2006). However, water droplets will not come to rest on the superhydrophobic surfaces and simply roll off if the surfaces are tilted even slightly. Such surfaces are also defined as self-cleaning surfaces because the contamination on them is easily removed by rolling droplets (Wu et al. 2009, Zhai et al. 2004). In nature, superhydrophobicity has been adopted by some plants, such as the leaves of lotus (Yu et al. 2014).

Up to now, many methods have been reported for constructing superhydrophobic surfaces on Al and its alloys by mimicking the surface of lotus leaves. Yin et al. fabricated a superhydrophobic coating on Al alloy through chemical etching followed by surface modification (Yin et al. 2012). Cho et al. constructed a superhydrophobic surface on aluminum foil by anodic oxidation method (Cho et al. 2007). Saleema et al. prepared a superhydrophobic Al alloy surface via a one-step process with the use of fluoroalkylsilane in a base medium (Saleema et al. 2010). These researches have paved the way for preparing a superhydrophobic surface on Aluminum or Al alloy surface. However, there are still some disadvantages need to be overcome, such as the environment problem of the chemical etching process and time consumption.

In this paper, we presented a simple, cost-effective and environmental-friendly way to prepare an aluminum alloy sheet with superhydrophobicity and self-cleaning properties. After modification with dichlorodimethylsilane, the hydrophobic silica nanoparticles were obtained. Through spraying hydrophobic silica nanoparticle suspension, the aluminum alloy sheet shows a contact angle of 159±1° and a sliding angle of 2°. It also shows perfect self-cleaning property. When the water droplet is dropped on the nano silica deposited aluminum alloy sheet covered with graphite powder, it rolls off the surface and carries the graphite powder away.
**2 EXPERIMENTAL PROCEDURE**

Al 6061 plates with dimensions of 20mm×20mm×3mm were used as the substrates. Before using, Al substrates were ultrasonically cleaned in ethanol and deionized water, respectively, then dried in air for 30 min. The hydrophobic silica nanoparticles were obtained by functionalizing the hydrophilic silica nanoparticles (16 nm diameter) with sufficient amount of dichlorodimethylsilane. In a typical process, silica nanoparticles (2 g) were dispersed in 2.5 v/v% dichlorodimethylsilane/toluene solution (40 mL) under stirring for 3 h. This procedure imparts hydrophobicity to the silica nanoparticles by immobilizing dichlorodimethyl groups on their surfaces. After multistep washing, the obtained hydrophobic silica nanoparticles were dried at 80 °C. Then, the hydrophobic silica nanoparticles (0.2 g) was dispersed in 5 g ethanol solution under stirring for 2 h, and the resulting suspension was sprayed onto Al 6061 substrates with a glass vaporizer. The resulting superhydrophobic silica nanoparticle deposited surfaces were dried at room temperature for 30 min.

FE-SEM (Field-emission scanning electron microscope) images were obtained on a Zeiss Supra 55 instrument at 5-10 kV. Prior to FE-SEM measurements, a thin Au layer (ca. 5 nm) was deposited on the specimens by sputtering. The water contact angle and sliding angle were measured with a SL100B apparatus at ambient temperature. The volume of the individual water droplet in all measurements was 5 µL. The average contact angle and sliding angle values were obtained by measuring the same sample at least in five different positions.

**3 RESULTS AND DISCUSSION**

Figure 1a and b are FE-SEM top-images of nano silica deposited aluminum alloy substrate with low and high magnifications, respectively. From the low magnification FE-SEM image (Figure 1a), it could be found that the coating surface was not smooth. We assumed that this kind of microscale roughness would be attributed to the aggregation state of the silica nanoparticles in the ethanol (Ogihara et al. 2012). The high magnification FE-SEM (Figure 1b) showed nanoscale porous structure. Numerous void spaces among individual nanoparticles are observed, and nanoscale roughness is evident. The silica nanoparticles ranged in size from dozens of nanometers to several hundreds of nanometers. The microscale roughness together with nanoscale roughness forms hierarchical structures, thus leading to superhydrophobicity (Li et al. 2014).

To study the surface wettability of silica nanoparticle deposited aluminum alloy surface, we measured the water contact angle and sliding angle, as shown in Figure 2. The treated aluminum alloy surface showed a high water contact angle of 159±1° (Figure 2a). Meanwhile the water droplets don’t come to rest on the surface when the sliding angle is 2°, suggesting low adhesion between water droplet and treated aluminum alloy surface (Zhang et al. 2013). As is known to all, the surface wettability can be described by the Wenzel (Wolansky et al. 1999) and Cassie-Baxter models (Johnson et al. 1964). Both two wettability states can result in a high contact angles. However, only the Cassie-Baxter model can lead to a very low sliding angle (Lin et al. 2013). Herein, Cassie-Baxter theory was employed to explain the mechanism of superhydrophobic behavior on the silica nanoparticle deposited surface. On the superhydrophobic treated aluminum alloy surface, the apparent solid-liquid contact is a real composite contact of solid-liquid-gas due to the hierarchical structures. In this composite state, air layer can be trapped in the micro cavities and nanopores among silica nanoparticles, and then water droplets will be suspended due to the “air cushion” underneath water droplets. Thus, the surface adhesion between droplets and superhydrophobic silica nanoparticle deposited
surfaces is extremely low and the water drops can slide off with a slight sliding angle.

(a) contact angle=159±1°

(b) Sliding angle=2°

Figure 2. Water droplets on the nano silica deposited aluminum alloy substrate with (a) a contact angle of 159±1° and (b) a sliding angle of 2°.

The silica nanoparticle deposited aluminum alloy surface also shows excellent self-cleaning property. The self-cleaning performance was investigated by applying graphite powders as contaminant on the surface. As shown in Figure 3, a layer of graphite powders was sprinkled onto the treated surface and then a water droplet (~10 µL) was dropped onto the contaminated surface. When the water droplet contacted the graphite powders, it just rolled off and carried the graphite powder away. After several sliding processes, the water droplet adsorbed the contaminants completely and then left a clean surface (Figure 3d).

Figure 3. Self-cleaning process on the silica nanoparticle deposited aluminum alloy surface: (a) the surface with graphite powder as a model of contaminant; (b-c) the contaminated surface with one water drop on it; (d) the contaminated surface after the sliding of water drop.
4 CONCLUSION

In conclusion, we have developed a facile and cost-effective spray-coating method to prepare superhydrophobic aluminum alloy surface. The treated aluminum alloy surface exhibited high water contact angle (159±1°) and low sliding angle (2°). Furthermore, the superhydrophobic aluminum alloy surface showed self-cleaning property. Thus, the aforementioned great properties make this method an excellent candidate to fabricate a superhydrophobic surface on an aluminum sheet for large scale application.

REFERENCES