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Fabrication of self-cleaning superhydrophobic surface on aluminum alloys with excellent corrosion resistance

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ABSTRACT

Aluminum (Al) alloys have been widely used in various fields while corrosion and contamination can cause serious problems to their functionality and aesthetic appearance. A self-cleaning superhydrophobic surface (SCSS) could be a potential solution to the problems. In this study, SCSS was fabricated via a facile and low-cost method with electrochemical anodization followed by surface modification using myristic acid. The surface morphology and composition were characterized by an atomic force microscope (AFM) and a field emission scanning electron microscope (FESEM) with attached energy dispersive X-ray spectrum (EDS). The static water contact angle (CA) and sliding angle (SA) on the SCSS were 155.6 ± 1.0° and 5.7 ± 0.2°, respectively. Electrochemical measurement results showed that the corrosion current density (J_{corr}) of SCSS was significantly reduced by 3 orders of magnitude and the corrosion potential (E_{corr}) shifted from −0.838 V to 0.403 V, indicating excellent corrosion resistance. The SCSS was further proven to function well after 9 month indoor exposure at room temperature. It also had good chemical stability after immersion in common solvents including deionized (DI) water and absolute ethanol for 36 h. In addition, the as-prepared SCSS also showed good self-cleaning performance.

1. Introduction

Aluminum (Al) alloys are abundant in nature. They are easy to handle and possess numerous predominant advantages, such as low specific weight, high specific strength and good conductivity. Therefore, Al alloys have been used in a wide range of applications, especially in aerospace, sports, transportation and civilian industries [1]. It is well known that Al and its alloys can develop a thin oxide layer in dry and non-salty environments, which could restrain their further corrosion. However, this thin layer is reactive and prone to corrosion and contamination in damp environments [2,3]. Consequently, further corrosion would lead to malfunction and limit their applications in wet and salty environments. To prevent such problems, it is desirable to form a corrosion and contamination resistant surface layer on Al and its alloys. This can be achieved by transforming the hydrophilic nature of Al and its alloy surfaces to be superhydrophobic.

A surface with a static water contact angle (CA) greater than 150° and a sliding angle (SA) less than 10° is defined as superhydrophobic. Such surface has attracted a great deal of interest in both fundamental research and practical applications due to its unique characteristics such as self-cleaning [4–6], water repellency [7], anti-icing [8–10], anti-corrosion [11–13] and oil–water separation [14–16]. The key factor to construct a superhydrophobic surface is the existence of a low energy layer on a rough hierarchical structure [17–21]. So far, a large number of approaches have been successfully used to develop superhydrophobic surfaces, including chemical vapor deposition [22], chemical etching [23], sol–gel [24], solution immersion [25], hydrothermal synthesis [26] and laser fabrication [27].

Up to now, a variety of methods have been reported for fabricating superhydrophobic surfaces on Al and its alloys. Yin et al. prepared a superhydrophobic coating on Al alloy via chemical etching followed by surface modification [28]. Barkhudarov et al. fabricated superhydrophobic films on Al surfaces from a precursor solution containing mixed alkoxides 3,3,3-trifluoropropyl-trimethoxysilane and tetramethyl orthosilicate through a variation of the aerogel thin film process [29]. Saleema et al. produced a superhydrophobic Al alloy surface via a one-step process using fluoroalkyl-silane in a base medium [30]. However, these methods are still subjected to certain limitations, and improvement is necessary in the future towards issues like processing time, scalability, complicated procedure and cost of the chemicals used.

In contrast, electrochemical processes are easy to apply, relatively fast and reproducible. Meanwhile, they are also effective techniques to control the surface morphology and roughness to construct large-area superhydrophobic surfaces [31]. The anodic oxidation of Al alloys is

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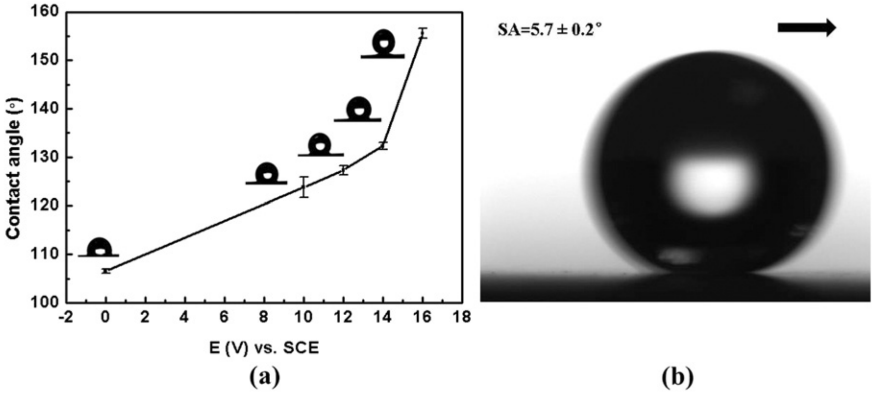

Fig. 1. (a) CA of Al alloy surface modified by molten myristic acid after different anodization voltages for 1 h; (b) SA of Al alloy surface modified by molten myristic acid under anodization voltage of 16 V for 1 h.

well known to be able to create uniform nanostructures and the anodic Al oxide (AAO) fabricated by anodization technique has gained enormous attention in both research and industrial applications [32–34]. Wang et al. prepared a superhydrophobic surface on Al substrate by anodization in phosphoric acid followed by low-temperature plasma treatment and subsequently trichlorooctadecyl-silane modification [35]. Liu et al. reported a superhydrophobic surface on Al alloy via anodizing in an electrolyte consisting of sulfuric acid, oxalic acid and sodium chloride, followed by polypropylene coating [36]. Jafari et al. created a superhydrophobic surface by coating RF-sputtered polytetrafluoroethylene on the anodized Al alloy surface [37].

Although a lot of superhydrophobic AAO surfaces have been developed in recent years, many practical problems occur when the products are launched. As we all know, one of the most important applications for superhydrophobic surfaces is corrosion resistance for metals and alloys. So incorporating superhydrophobicity through anodic oxidation is a novel process towards corrosion protection [38] for Al and its alloys. However, limited research was conducted on their corrosion resistance [39–41]. Besides, the lack of durability and stability is also a common weakness for most of superhydrophobic surfaces, which restricts their potential prospects in outdoor application. Many superhydrophobic surfaces would easily lose the superhydrophobicity after exposure to harsh environments, such as solvents and hot liquids, indicating poor chemical stability [42]. It is noted that the previous reported superhydrophobic surfaces are inclined to use cool water under ambient temperature to characterize their repellency, while there is lack of knowledge about their resistance to hot water (50 °C or higher) or solvents [39,43,44]. It is important and necessary to fabricate superhydrophobic Al alloy surfaces with both excellent corrosion resistance and chemical stability from the real application point of view. To

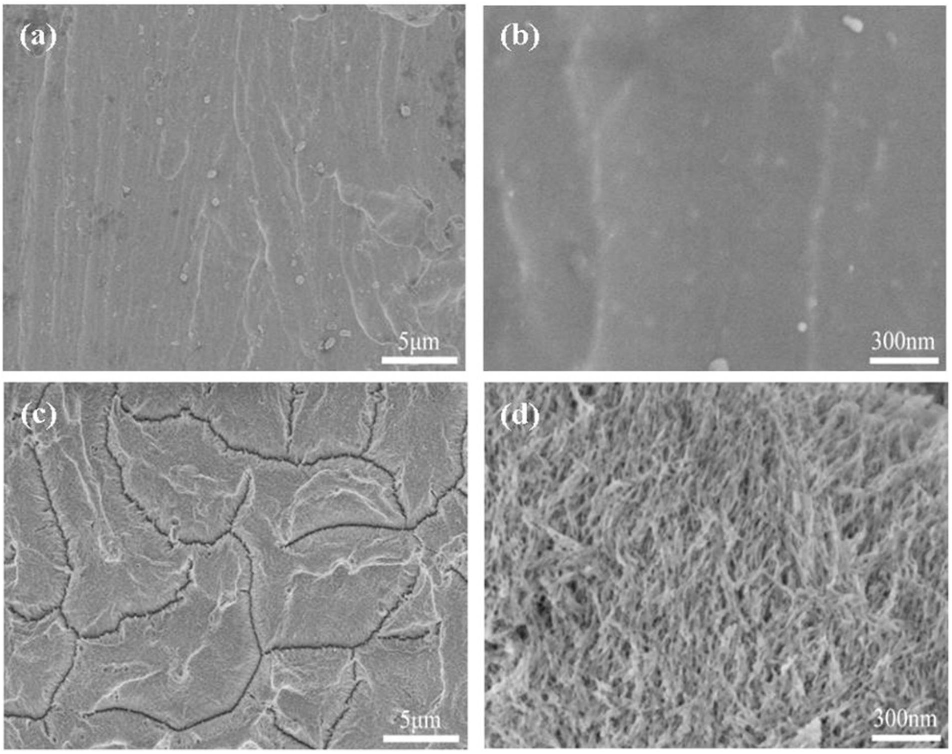

Fig. 2. FESEM images: (a)–(b) Al alloy surface modified by molten myristic acid without anodization at different magnifications; (c)–(d) SCSS.