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# Fabrication of biomimetic superhydrophobic steel surface under an oxygen rich environment

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ABSTRACT

A novel and facile approach was proposed to fabricate superhydrophobic surface with similar micro- and nanostructures of lotus leaf on the steel foil. The acidic solution was used to grow $Fe_3O_4$ nanosheet films consisted of hydrochloric acid and potassium chloride under an $O_2$ rich environment. The as-prepared superhydrophobic steel surfaces had water CA (contact angle) of $166 \pm 2°$. The water SA (sliding angle) was less than 2°. In order to estimate the drag reduction property of the as-prepared surface, the experimental setup of the liquid-solid friction drag was proposed. The drag reduction ratio for superhydrophobic surface was 61.3% compare with untreated surface at a flow velocity of $1.66\ m\ s^{-1}$.



## 1. Introduction

Wettability is a very important aspect of materials and governed by both the surface chemical composition and geometric structure [1–9]. Since, superhydrophobicity of lotus leaves was revealed by Barthlott and Neinhuis, superhydrophobic surfaces have attracted extensive attentions in both academia and industry. Many researches on superhydrophobic surfaces have been inspired by mimicking natural models such as the superhydrophobic lotus leaf which possesses dual scale micro-/nanostructures along with a waxy coating [10]. The wetting or dewetting behavior of solid materials is often determined by both surface roughness and chemical composition. The hydrophobicity can be greatly enhanced by means of increasing surface roughness and lowering surface free energy [11–13]. Therefore, artificial superhydrophobic surfaces have been manufactured mainly by two methodologies: creating micro-/nanostructures on hydrophobic substrates, or chemically modifying a micro-/nanostructured surface with materials of low surface free energy. In recent years, a variety of methods had been developed to mimic surface for the fabrication of many artificial superhydrophobic surfaces [14–18].

As an important engineering material, steel is widely used in many industrial fields, including petrochemical, construction, maritime and aviation industries. The fabrication of superhydrophobic steel surface has attracted much attention largely because of their practical or potential engineering applications. Many techniques have been proposed to generate superhydrophobic surfaces on the steel, such as solution immersion, nano coating, electrochemical deposition, and laser fabrication [19,20]. Zhao presented a simple method for fabricating stainless steel-based superhydrophobic surfaces using a femtosecond laser [21]. Sethi reported the synthesis of superhydrophobic coatings on the steel using carbon nanotube (CNT) mesh structures [22]. However, many of these methods subject to certain limitations, such as special equipment, expensive material, complex process, long period, and poor durability. As a result, it is highly desirable to develop a simple, commercial, time-saving, and reliable method to fabricate stable superhydrophobic surface. Nonetheless, chemical etching is an inexpensive and easily controlled approach compared with the other methods [23,24]. However, the electrochemical machining and chemical etching methods require the acid corrosive procedure, while sulfuric acid, chlorhydric acid, nitric acid, and hydrofluoric acid are often used. These acids need high concentration to fabricate the superhydrophobic surface, and hazard to the environment and the health of the operator. Herein, we present a novel method to fabricate a superhydrophobic surface on a steel sheet via chemical etching and oxidation technology in acidic solution with low concentration. The

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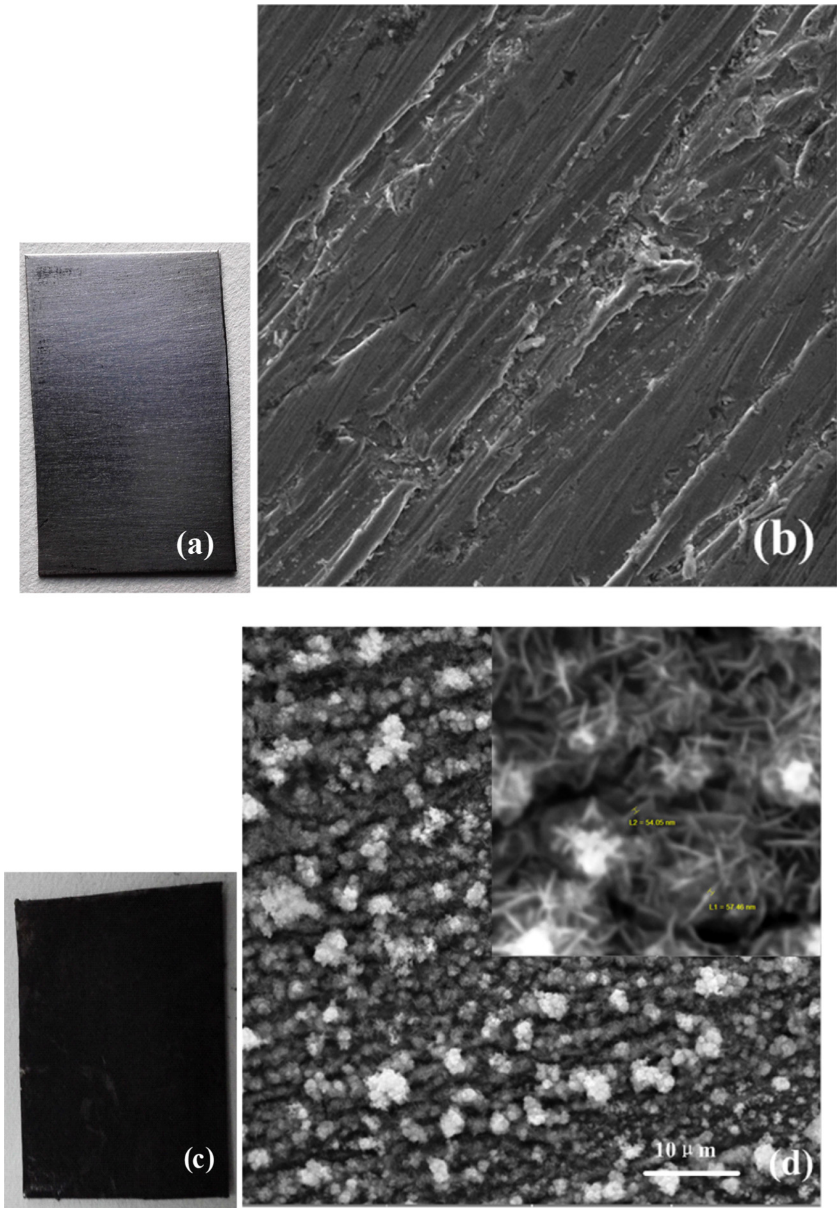


**Fig. 1.** Optical photographs taken at two slightly different orientations perpendicular to Fe substrate surface (a) before and (c) after grow for 25 min in acidic solution with introduced oxygen bubbles. (b and d) Corresponding SEM images of the Fe substrate surfaces and $Fe_3O_4$ films. Large area uniform synthesis of $Fe_3O_4$ nanosheets is observed.

acidic solution used in the growth process consisted of hydrochloric acid and potassium chloride under an $O_2$ rich environment. The steel substrate was grown the $Fe_3O_4$ film with nanoflower-like structure. The as-prepared surface after modified with fluorinated silane shows superhydrophobic property with a static water CAs of $166 \pm 2°$. The sliding angle is lower than 2°. Moreover, the superhydrophobic surface possesses long-term stability and chemical stability.

## 2. Experimental

### *2.1. Materials and methods*

All chemicals were analytical grade reagents and used as received without further purification. A typical experiment procedure was as follows: steel foils with thickness of 0.3 mm and dimension of 2 cm × 2 cm were polished with 800#, 1200#, and 1700# sandpaper in turn, and then cleaned ultrasonically with acetone and deionized water to remove grease, respectively. The acidic solution used in the growth process consisted of hydrochloric acid (HCl) and 0.2 M potassium chloride (KCl) [25]. The pH value of the solution was adjusted to be around 3 as indicated by a pH paper. 200 mL of the solution was loaded into a glass beaker and then heated to around 70 °C by a hotplate. A steel foil sample was then immersed into the solution. The steel foil thus provided the raw Fe material needed for nanostructure formation of iron-oxide. To expedite the growth and etching of iron-oxide with this technique, we introduced pure oxygen bubbles at the flow rate of 160 sccm to the solution. The chemical oxidation process is similar to other $Fe_3O_4$ nanostructures growth by the conventional hydrothermal technique [26,27]. A magnetic bar rotated at a rate of 120 rpm provided continuous stirring to the solution during the growth processes. After reacting for a certain time, it was picked out and then immersed into 50 mL of distilled water for about 1 h before dried in $N_2$ environment. Finally, these samples were immersed in an ethanol solution of fluorinated silane (FAS, 1H,1H,2H,2H-perfluorooctadecyltrichlorosilane) of