Preparation and Drag-reduction of Porous Superhydrophobic Surface on Stainless Steel

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ABSTRACT

The non-wetting behavior was originally found at lotus leaf surface, which drew great attention of scientists in lots of fields [1]. Until now, more and more preparation techniques [2-4], such as plasma treatment, template methods, electrospinning, sol-gel methods, electrochemical methods and so on, have been invented. Although these results are interesting, the fabrication processes are time-consuming and too complicated for most practical applications. As an engineering material, the stainless steel has been used for applications in many industrial fields. The fabrication of a superhydrophobic surface on steel has attracted significant attention. However, it has been very difficult to fabricate an applicable engineering superhydrophobic surface on stainless steel so far, because the textured films easily fall off the stainless steel substrate. For example, the superhydrophobic surface fabricated by thermal evaporation was not homogeneous with the substrate, so the film is probable to fall off from the stainless steel.

In this paper, the porous surface with micro/nanoscale hierarchical structure was obtained by anodizing 304 stainless steel foils at room temperature, and the electrolyte contains 5wt% perchloric acid in ethylene glycol. Fig. 1 shows the SEM images of stainless steel samples after electrochemical etching for different time. Experiments find that the surface morphology varied with the etching time, and the diameter of the micro-pore grows with the increase of the reaction time. After a series of tests, we have concluded the optimum etching time. The electrochemical oxidation of iron was based on the fact that metal etching is formation and dissolution of its oxide by the perchloric acid. The ethylene glycol has been proven to be the most effective electrolytic medium in rapid synthesis of iron (III) oxide nanoporous structure in constant-current anodization of iron. The energy-dispersive spectroscopy (EDS) and X-ray photoelectron spectroscopy (XPS) show the chemical composition and the percentage of some chemical elements of the as-prepared sample, such as Fe, Cr, O and C. The metal oxides composition can be found after analyzing the XPS results. The spectrum of the as-received sample is shown in the Fig. 2. The dominant peaks are contributed by the Cr^{3+} located at 576.3 eV and 586.2 eV. For the Fe 2p spectra, there is a dominant peak at 713.7 eV corresponding to the Fe^{3+} state. Combining the peak of the O 1s spectra, we can speculate the component of oxides on the substrate. These reveal that, except for some compounds of iron and chromium, Fe_2O_3 and Cr_2O_3 are the prevailing oxides present the surface.
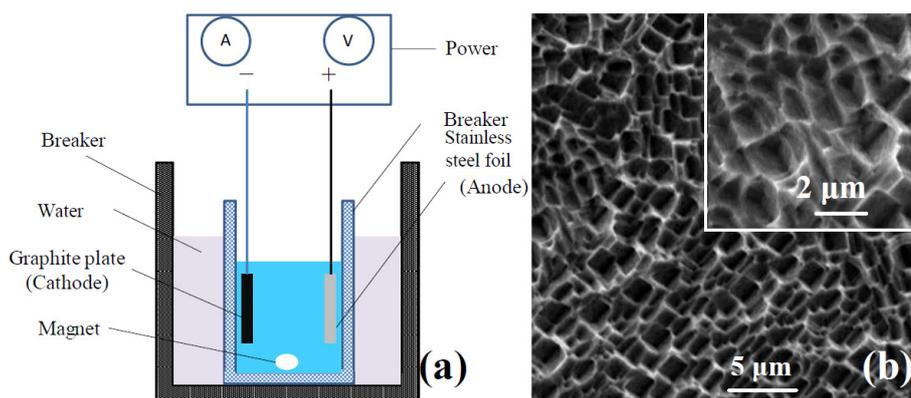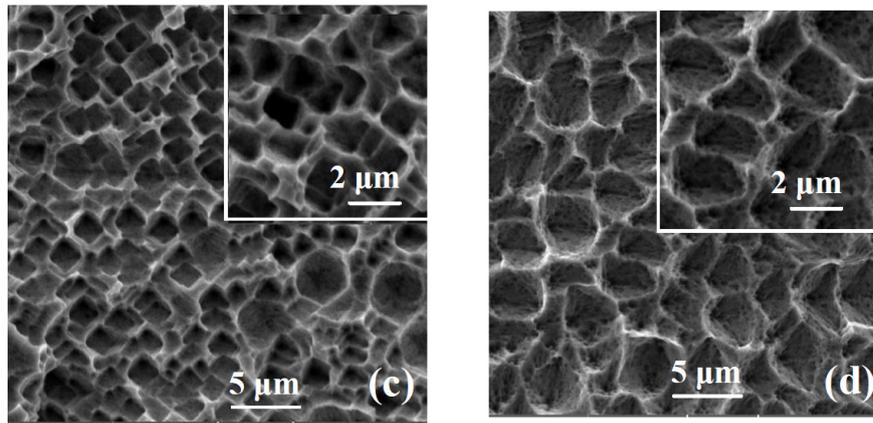
Figure 1 (a) Schematic representation of the experimental setup using the electrochemical anodization (b) FESEM images of the diverse resultant stainless steel surfaces prepared at various anodization time: (b) 20 min, (c) 30 min, (d) 40 min.
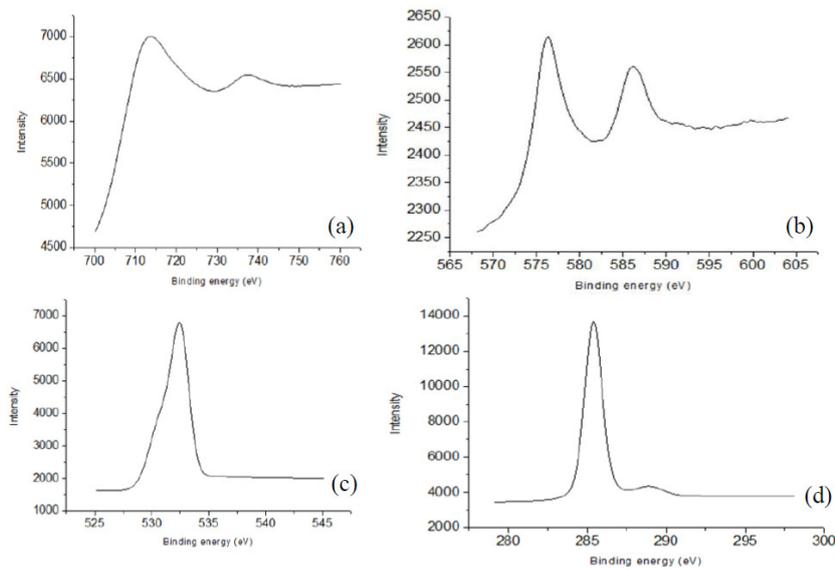

Figure 2 XPS results of stainless steel sample after electrochemical anodization for 30 min (a) spectra of Fe 2p, (b) spectra of Cr 2p, (c) spectra of O 1s, and (d) spectra of C 1s.

After the modification with silane regent, the wettability of the as-prepared sample is successfully converted from superhydrophility to superhydrophobicity. As shown in Fig. 3 the water CAs for the sample surfaces is 158 ± 2°, and SAs is less than 4 ± 2°. In order to estimate the drag reduction property of the superhydrophobic surface, the experimental setup of the liquid/solid friction drag is reported. As for the drag reduction property of the prepared 304 stainless steel surface, the superhydrophobic surface has enormously improved the drag reduction ratio of the stainless steel foil, at approximately 20%-50% (shown in Fig. 4). The result is that the micro/nanostructures on the superhydrophobic surface can trap bubbles, and the surface can produce slip and reduce the friction resistance. Bearing this in mind, we construct superhydrophobic surfaces that have numerous technical applications in the drag reduction field.
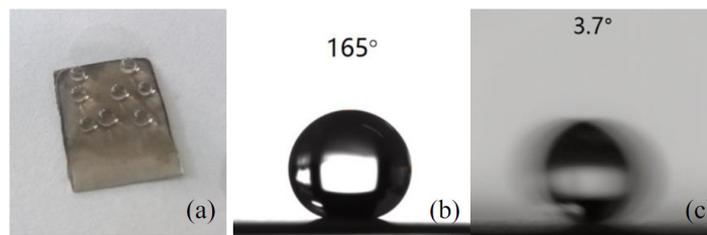

Figure 3 (a) The real photograph of the water droplet on the prepared superhydrophobic surface, (b) and (c) the CAs and SAs of the droplet on the prepared surface, respectively.
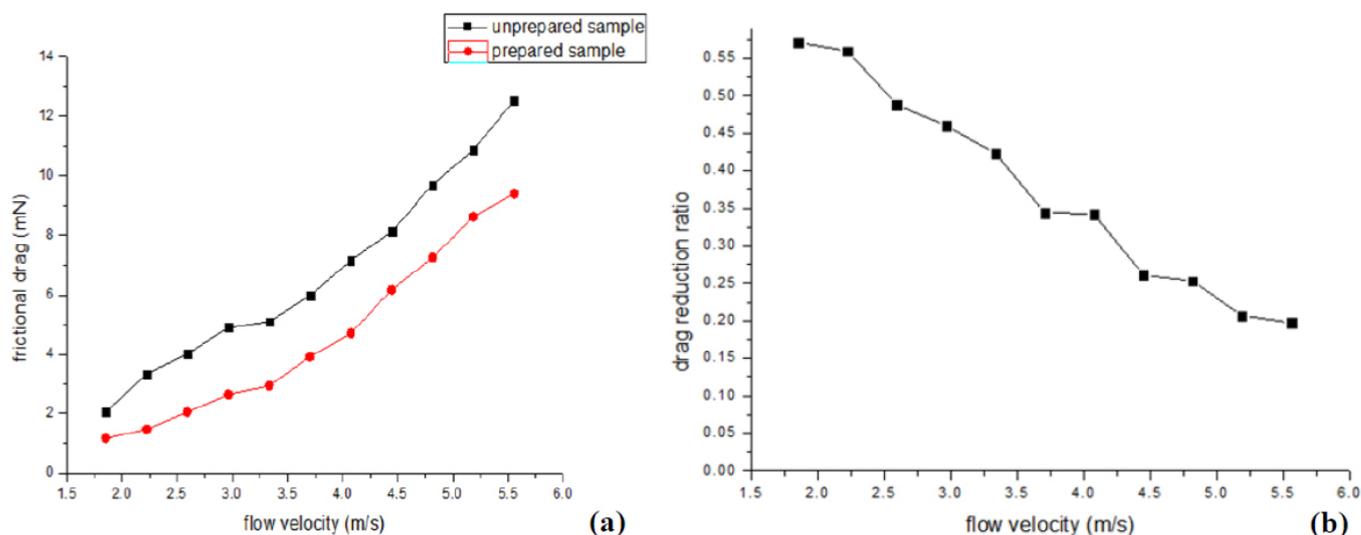
Figure 4 (a) friction drag versus the velocity of the water flowing over surfaces with different adhesion property (B) drag reduction ratio of different flow velocity.

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