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Morphological effect governed by sandblasting and anodic surface reforming on the super-hydrophobicity of AISI 304 stainless steel

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ABSTRACT

Super-hydrophobicity, enabling self-cleaning and antifouling capability, has attracted intensive researches by using different surface techniques. To achieve super-hydrophobicity on metal surfaces, morphological control of the surface shares equal importance with surface energy control. This study aims to develop a micro/nano coexisted surface morphology presenting super-hydrophobicity on an AISI 304 stainless steel, which was previously prepared by sandblasting and anodic reforming followed by a plasma treatment. By proper choice of the sand material, micrometer-scale morphology was shaped by sandblasting. Meanwhile, the nanometer-scale sub-feature can be reformed through the use of anodic electrochemical treatment, where the alkali electrolyte concentration, discharge voltage, and processing time were carefully controlled. By doing so, super-hydrophobicity perform well on AISI 304 stainless steel after Steel Wool test.

1. Introduction

Super-hydrophobic surfaces with the water contact angle greater than 150° have numerous applications of self-cleaning, non-wetting, anti-fogging, and antifouling attract intensive research and are broadly applied to industry and daily life [1]. There are two crucial criteria to achieve super-hydrophobic surfaces: low surface energy and hierarchical (micro and nano) surface topography [2,3]. Therefore, in order to further increase the hydrophobicity of a surface, it is necessary to micro/nano structure it. This leads to the amplification of the hydrophobic character of the surface, which can be explained by two different models assuming either that the liquid is in the contact with all the parts of the irregular surface (Wenzel's model [4]), or that the drop sits on the surface protrusions and thus does not wet the entire surface (Cassie-Baxter's model [5]). Artificial super-hydrophobic surfaces can be achieved by many different methods, such as electrochemical treatment, template synthesis, sol-gel processing, lithography, layer by layer deposition, plasma polymerization, and so on [6].

Sandblasting is a way of abrading a surface, such as concrete or metal, by a stream of sand or other abrasives which is ejected at high speed from a nozzle and causes microscale unevenness on the target surface [7]. The anodic oxidation treatment may be achieved by altering the surface roughness, porosity, and chemical composition. Moreover, simple control of the pore dimensions, such as diameter, length, and density, by varying the anodizing conditions would be advantageous [8–10]. The formation of anodic oxidation depends on the anodic voltage, the temperature of the solution, and the anodizing time [10].

Among them, electrochemical treatment is a relatively simple and cheap technique and consists of anodic and cathodic treatment. Anodic oxidation is the main anodic technique. Electrophoretic and cathodic depositions are the cathodic techniques. By anodic oxidation, super-hydrophobicity may be achieved by altering the surface roughness, porosity, and chemical composition. Fluorocarbon coatings are applied in various fields such as antifouling biomedical implants, microelectronics, integrated sensors, and so on due to their unique properties: inert, hydrophobic, oleophobic, good chemical resistance, weatherability, etc. It's worth noting that polymers with perfluoroalkyl chains exhibit low surface energy and high liquid repellency [11].

As an important engineering material, stainless steel is widely used in many applications, including construction, transportation parts, heavy industry, kitchenware, food industries, and medical equipment. Its broad use is the result of a unique and useful combination of high corrosion resistance and excellent mechanical strength. Stainless steel is a broad term used to describe iron-based metals that contain greater than 12% chromium and have resistance to corrosive environments. Stainless steel alloyed compositions vary greatly based upon the desired application, with different alloy mixtures imparting varying corrosion resistance, hardness, and mechanical strength. Iron — chromium-nickel alloys are known as

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Table 1
The deposition process parameters for preparing the hybrid ET-FC films.

Deposition parameters	Values
Substrate temperature	Near room temperature
Working pressure (Pa)	47.33 ± 1.72
Pulsed frequency (KHz)	50
T_{on}/T_{off}	1/40
C_4F_8 flow (sccm)	13
Deposition time (min)	30

the 300 series of stainless steel, and are the most commonly used. 304 stainless steel is composed of 18 wt% chromium and 8 wt% nickel, with iron making up the majority of the remaining composition [12].

This study aimed to develop hybrid nano- and micro-structured super-hydrophobic films on the AISI 304 stainless steel substrates by electrochemical treatment combined with plasma-polymerized fluorocarbon coating to improve the efficiency and lifetime of the super-hydrophobic engineering materials. The microstructures, mechanical properties, surface water contact angle (WCA) of the deposited films were examined.

2. Experimental

In this study, the AISI 304 stainless steel substrates (round shape, 13 mm in diameter, and 1.5 mm in thickness), which were clinically made into the dental appliances, were sandblasted with 50 μm alumina. After sandblasting, the substrates were ultrasonically cleaned in ethanol. The electrochemical technology was used to develop nano- and micro-scale morphology on the surfaces of AISI 304 stainless steel. The apparatus for electrochemical measurement consists of a potentiostat instrument, which is composed of a direct current (DC) power supply and a pulse power controller (SPIK2000A-06, MELEC GmbH, Germany) and controlled by a personal computer with dedicated software, a negative electrode as the counter electrode by a stainless steel, and a positive electrode as working electrode for the specimen. Sodium chloride (1 M NaCl, 20 ml) and sodium hydroxide (5 M NaOH, 10 ml) of alkaline electrolyte solution were used at the voltage of 30 V for 4 min. Subsequently, a fluorocarbon coating will be deposited on the surfaces of the pre-treated substrates by a pulsed-dc plasma enhanced chemical vapor deposition (PECVD) technique. In the deposition chamber of the plasma polymerization system, the pre-treated AISI 304 stainless steel substrate by electrochemical treatment (ET) was placed on the lower plate (cathode), and an ENI bipolar pulsed-dc power supply was connected with the upper plate (anode) to generate glow discharge plasma. Prior to deposition, the AISI 304 stainless steel substrates were cleaned by oxygen plasma bombardment for 3 min at 50 W. Then C_4F_8 was passed into the chamber for 30 min at 50 W to obtain the hybrid electrochemical-flourocarbon (ET-FC) films. The detailed deposition process parameters are listed in Table 1, and schematic drawings of the deposition system and electrochemical cell are shown in Fig. 1.

The Hitachi S-4800 field emission scanning electron microscope (FESEM accelerating voltage 3.0 KV) was used to observe the surface morphology of the deposited films. A scanning electron microscope equipped with an energy dispersive spectrometer (EDS) was used

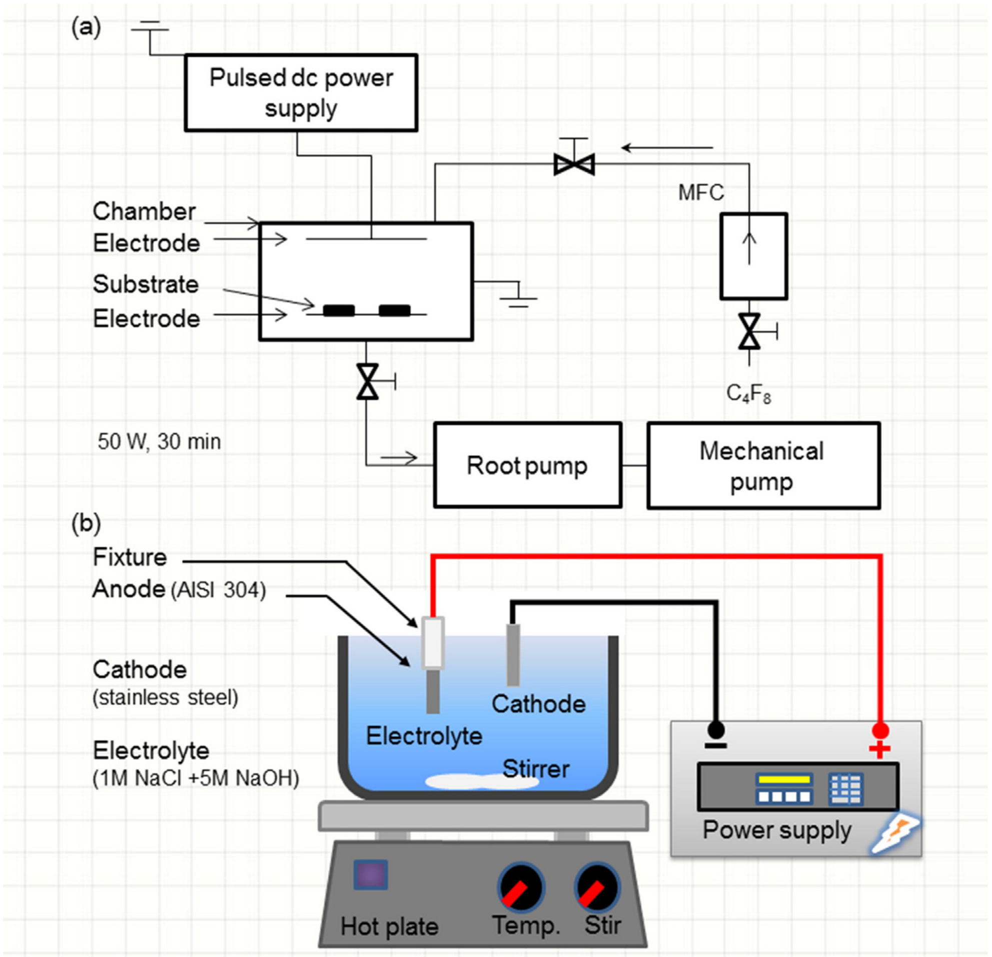

Fig. 1. Schematic drawings of (a) the deposition system and (b) electrochemical cell.

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