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Fabricating an enhanced stable superhydrophobic surface on copper plates by introducing a sintering process

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ABSTRACT

The superhydrophobic surface has the potential for use in functional applications. This study reports a novel method for coupling a sintering process with a traditional technique based on the solution-immersion method to prepare a stable superhydrophobic surface. The use of a sintering process aids in the enhancement of the adhesive strength and acid resistance of the surface structure. The advantage of using this method lies in its flexibility in regulating the processing parameters and functional behaviours. The influences of different processing parameters were experimentally investigated. The surface treated with a sintering process remains superhydrophobic with a contact angle of >150° after immersion in an acid solution for 120 h. The sintered surface maintains good integrity after experiencing ultrasonic vibration for 5 min. The results indicate that the sintering temperature must be optimized to increase the adhesive strength and maintain sufficient hydrophobicity. The modification time is an important factor related to the level of hydrophobicity.

1. Introduction

The development of a superhydrophobic surface has attracted increasing attention in the field of functional materials and components. A surface with a large water contact angle of more than 150° is defined to be superhydrophobic. However, occasionally the contact angles of soft porous materials (e.g., cotton wool) are difficult to determine. Therefore, the water bouncing test is more suitable for identification of the water-drop behaviours on a surface [1]. A superhydrophobic surface exhibits a variety of interesting behaviours for practical applications in oil–water separation [2,3] as well as anti-icing [4,5], anti-drag [6,7], and anti-corrosion [8,9] purposes. Theoretically, the superhydrophobicity surface must possess an appropriate roughness and lower surface energy [10–12].

Various polycrystalline metals, such as aluminium, copper and zinc, have been used to prepare superhydrophobic surfaces. As an important raw material for metal processing, copper has been widely used due to its advantages, such as good machinability, high thermal and electrical conductivity, and good ductility. The fabrication of a superhydrophobic surface on copper has shown great potential for use in functional applications. In recent years, significant advances in terms of superhydrophobic copper surfaces have been reported. A typical method for fabricating a superhydrophobic surface on a copper plate involves the creation of micro/nanostructured roughness on the material surface followed by treatment with a modifying agent. Many methods for creating rough surfaces have been developed including the template method [13], electrochemical deposition [2,14], electrochemical anodization [15], and solution immersion [16,17]. In addition, a low surface energy material must be used as a modifier.

Many studies have employed the solution-immersion process because it is simple and efficient. Zhang et al. [17] fabricated a superhydrophobic copper surface via direct oxidation and modification with lauric acid. Pan et al. [18] fabricated a superhydrophobic surface by immersing the copper plate in a mixed aqueous solution consisting of sodium hydroxide and potassium persulfate followed by modification of the surface with dodecanoic acid. Xu et al. [19] prepared a superhydrophobic surface on a commercial copper-foam substrate by immersing it in a 0.05 M ethanol stearic acid solution at room temperature for several days. Chen et al. [20] prepared a superhydrophobic surface on a copper foil by combining facile alkali assisted surface oxidation and modification based on the use of 1H,1H,2H,2H-perfluorodecyltriethoxysilane (FAS). Chen et al. [21] fabricated a compact and uniform superhydrophobic film on a copper substrate using a one-step solution-immersion process. A mixed solution consisting of 1-dodecanethiol and tetradecanoic acid was used as the modifier, and the maximum contact angle reached 160°. Wu et al. [22] produced a superhydrophobic surface based on copper hydroxide nanoneedles. A thin copper layer

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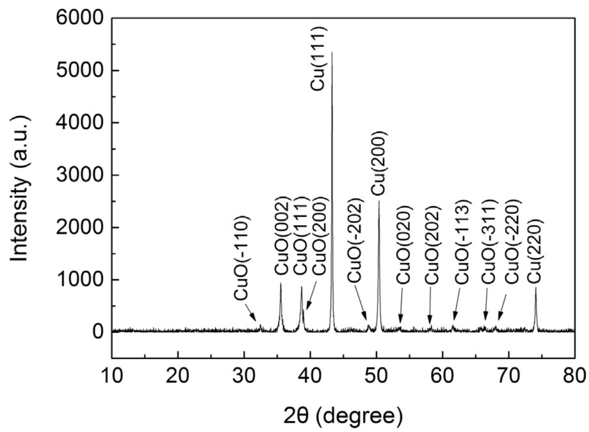

Fig. 1. XRD patterns of the oxidized copper plate surface.

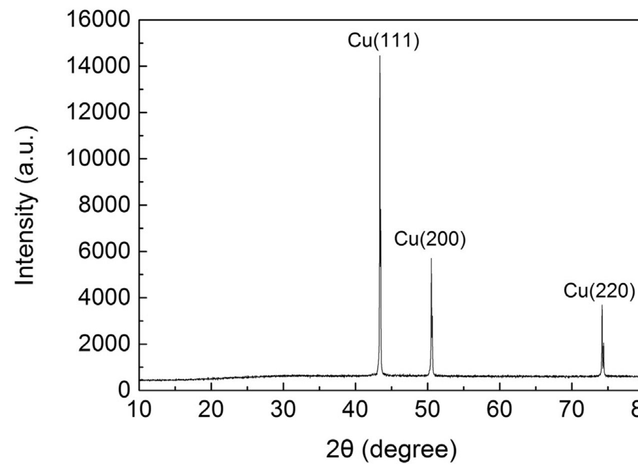

Fig. 2. XRD patterns of the sintered copper plate surface.

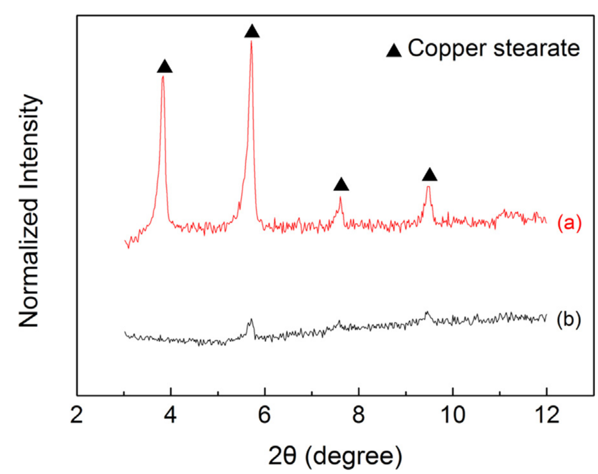

Fig. 3. XRD patterns of the copper plate surface modified for (a) 48 h and (b) 24 h.

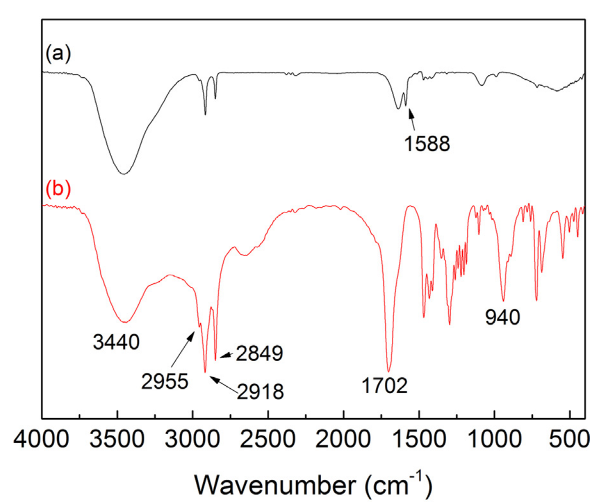

Fig. 4. FTIR spectra of (a) $Cu[CH_3(CH_2)_{16}COO]_2$ powder scraped from the modified copper surface and (b) stearic acid.

was anodized in a 2 M potassium hydroxide solution followed by reaction with n-dodecanethiol to form a superhydrophobic coating with a contact angle greater than 150°. Liu et al. [23] prepared a hierarchical CuO architecture consisting of densely packed nanoplates and nanoribbons using a room-temperature solution-immersion process to successfully achieve a contact angle of about 155° on a Cu foil.

Although many studies using the solution-immersion method have been reported, the adhesive strength and acid resistance of the superhydrophobic copper surface have received limited attention. The degree of adhesive strength reflects the firmness of the connection between the microstructures and the substrate. For practical applications, the surface may be exposed to a harsh environment, which poses a challenge. In addition, the micro- or nanoscale structures formed on the surface typically have very weak mechanical properties. The surface microstructures may be desquamated by scuffing or vibrating, which inevitably results in a loss of the superhydrophobic ability [24]. Therefore, the adhesive strength of a superhydrophobic surface must be evaluated. The surface microstructures might also be corroded in an acidic environment. Therefore, its acid resistance is also an important index for overall performance optimization. For example, if the superhydrophobic surface is used as a mass transfer interface in a chemical reactor, the surficial material may encounter severe gas or liquid flow concussion and possibly corrosive medium. Before the material or component is employed in an extreme environment, these issues must be addressed. In this study, we focus on how to enhance the adhesive strength and acid resistance of the superhydrophobic surface based on a copper material. A novel approach introducing a sintering process to the traditional solution-immersion method was developed to enhance the fastness and stability of the modified superhydrophobic structure. The influences of different processing parameters on the surface wettability were evaluated. The surface microstructures and composition were also characterized.

2. Materials and methods

2.1. Materials

This study employed the following reagents: deionized water, sodium hydroxide, hydrochloric acid, potassium persulfate, ethyl alcohol, stearic acid, acetone, and sulfuric acid. All of these reagents were of analytical grade. The purity of the copper plate (Yueqing Jintai Copper Industry, Inc., Wenzhou, Zhejiang, China) was 99.8% and the size of each sample was 20 mm × 20 mm × 2 mm.

2.2. Preprocessing

First, both sides of the copper plate were polished using 600# sandpaper to remove the scratches, pits and oxide layer on its surface. Second, the sample was cleaned with deionized water using an ultrasonic cleaner. Then, the cleaned sample was immersed in a