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Versatile aluminum alloy surface with various wettability

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ABSTRACT

Various geometric microstructures on aluminum alloy surfaces were fabricated simply through SiC paper rubbing, and the wettability of the obtained surfaces was investigated thoroughly. The water contact angle increased firstly with the increasing particle size of the sandpaper, and then declined with further increase of the grits size, exhibiting a hydrophilic–hydrophobic–hydrophilic transition. The effect of surface geometric microstructure on the wetting behavior of aluminum alloy can be well rationalized in terms of the Cassie–Baxter model by considering the surface energy gradient. The present results not only enhance the in-depth understanding of the mechanism for the significant role of surface microstructure on the wettability of aluminum alloy, but also explore promising applications of versatile metallic surface in industries.

1. Introduction

The wettability of solid materials has attracted enduring attractions in last decades because of their unique properties and importance in both fundamental research and practical applications [1]. Previous literatures [2–4] reported that the wettability on a solid surface is determined by both surface geometrical structure/roughness and surface free energy. Therefore, methods on fabrications of superhydrophobic surfaces have mainly focused on the combination of reduced surface energy and enhanced surface roughness. For example, in the past few years, much attention has been paid to mimic the morphology of biological materials (such as lotus leaves which are superhydrophobic and non-stick in nature [5]), in order to get various micro/nanoscale topographic features to enhance the surface wettability [2,6,7], such as the artificial self-cleaning surfaces with a water contact angle (CA) larger than 150° and a water sliding angle (WSA) less than 10° [8]. In addition, most superhydrophobic surfaces were principally made from the low surface energy materials, such as polymers, glasses, carbon nanotubes and silicon nanowires. However, these materials usually have low mechanical strength and poor bonding strength between the superhydrophobic film/coating and the substrate, leading to a short lifespan in service, and thus limits their practical applications [9,10].

Recently, efforts have been devoted to the fabrication of superhydrophobic surfaces on metallic materials. However, owing to the fact that metallic surfaces are intrinsically of high surface energy, the surface roughness consequently plays a crucial role in the fabrication of superhydrophobic metallic surface [9]. For instance, superhydrophobic surfaces have been fabricated on stainless steel, high speed tool steel and titanium alloy through femtosecond laser irradiation [11], obtained on copper substrate through electrochemical crystal growth of cobalt hierarchical structure [12] and porous micro-nanoscale structures construction [13]. The superhydrophobic surfaces were also constructed based on the zinc substrates through replacement deposition of platinum [14]. More recently, bulk metallic glasses (BMGs) have been introduced to fabricate superhydrophobic surfaces through hot-embossing micro-patterns [9,10,15], taking advantage of BMGs' superplasticity in the supercooled liquid region (SCLR) [16-23]. Aluminum alloy is another important metallic material in the superhydrophobic metal surfaces research because it is abundant in nature, easy to handle, high technological value and wide range of industrial applications [24]. The superhydrophobic aluminum alloy surfaces have been fabricated via anodizing and polymeric coating [25], boiling water treatment accompanied by stearic acid modification [26], chemical etching followed with surface modification [1,27,28], wet chemistry synthesis [29] etc. However, the above methods on the fabrication of superhydrophobic metallic surfaces exist some of following disadvantages, such as expensive materials or special equipment required, long time taking, complicated process control and environment-unfriendly, which severely hindered the extensive applications of superhydrophobic surface [25].

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It is also notable that, almost all researches have mainly focused on the superhydrophobic property of the metal surfaces. In general, hydrophobic and hydrophilic solid surfaces exhibit extensive applications, for example, the hydrophobic surfaces are widely used in machine building, construction and textile production [30] etc; the hydrophilic surfaces can be used as medical devices [31] and lubricated surface [32]. However, little attention has been paid to these hydrophobic and hydrophilic metallic surfaces.

In this work, the attention is focused on the hydrophobic and hydrophilic aluminum alloy surfaces that can be easily fabricated by sandpaper rubbing. It will be shown that the water contact angle increased firstly with the increasing particle size of the sandpaper, and then declined with further increase of the grits, exhibiting a hydrophilic–hydrophobic–hydrophilic transition. The hydrophobic and hydrophilic aluminum alloy surfaces also unfold a possible application in antennas, lubricated surface and versatile transport of liquid microdroplets.

2. Experimental

The 5A02 aluminum alloy [33,34] used in this work was provided by the Aluminum Corporation of China as 2.0 mm thick rolled plate in the annealed condition. Samples with dimension of 10 mm × 10 mm × 2 mm were fabricated by wire-cutting from the annealed plates. In order to fabricate various geometric structures on aluminum alloy surface, the surfaces of the specimens were scratched by SiC paper with grits ranging from 240 to 3000 meshes, and rubbed in one direction to obtain regular profiles. In order to avoid the effect of surface oxidation and keep the identical surface energy, all rubbed aluminum alloy specimens were cleaned using an ultrasonic bath in acetone, and then dried in vacuum chamber before taken out for contact angles (CAs) measurement. Droplets (2 μl) of distilled water were applied to the surface and the static water contact angles (CAs) were measured in air with a Kino SL2000 contact angle system at ambient temperature [9,10]. In addition, the morphologies of the rubbed aluminum alloy surfaces were subsequently characterized by laser scanning confocal microscope (Keyence VK-X200 series).

3. Results and discussion

Fig. 1 shows the 3D profiles of the four typical aluminum alloy surfaces rubbed by SiC paper with minimum grit of 3000, 1500, 600 and 240 meshes. An almost mirror-like surface can be seen clearly when the specimen was polished with minimum grit of 3000 meshes, as depicted in Fig. 1(a). However, there are some geometric protrusions along the scratched direction distribute on the aluminum alloy surface, when the minimum grit increases to 1500 (see Fig. 1b) and 600 meshes (see Fig. 1c). The geometric protrusions become more conspicuous when the aluminum alloy surface was only rubbed by 240 meshes SiC paper, as described in Fig. 1(d).

To further reveal the difference in geometric structures on the rubbed aluminum alloy surfaces, the line scanning profiles perpendicular to the rubbing direction (see the dotted line in Fig. 1b–d) were measured, and the results are described in Fig. 2. On the whole, the cross-sectional morphology presents a sawtooth periodic profile, but these profiles exhibit a distinct discrepancy in altitude difference (H) between adjacent peaks and troughs. The average value of H is very small (about 0.22 ± 0.03 μm, as shown in Fig. 2a) on the smooth aluminum alloy surface (rubbed by 3000 meshes SiC paper), but increases sharply to about 3.69 ± 0.06 μm when the minimum grit of the sandpaper increases to 1500 meshes (see Fig. 2b), and shows a boosting tendency with growing grit size ($H = 6.57 \pm 0.05$ μm as depicted in Fig. 2c). However, the value of H decreases back to about 4.39 ± 0.08 μm with further increase of grit size (see Fig. 2d), accompany with the largest value of peak width (W) that growing with the particle sizes.

The corresponding CA on the rubbed aluminum alloy surfaces was measured with a water droplet (2 μl in volume) and the results are displayed in Fig. 3. The CA is 26.7° on the smooth aluminum alloy surface (Fig. 3a), exhibiting a hydrophilic property, but it increases to 59.7° (Fig. 3b) and 92.6° (Fig. 3c) when the minimum grit size increases to 1500 and 600 meshes, respectively, indicating a hydrophilic–hydrophobic transition. With further increase in grit size to 240 meshes, CA decreases to 57.2°, exhibiting hydrophilic property again (Fig. 3b). The variation of CA with grit sizes is summarized in Fig. 3(e), which clearly presents the

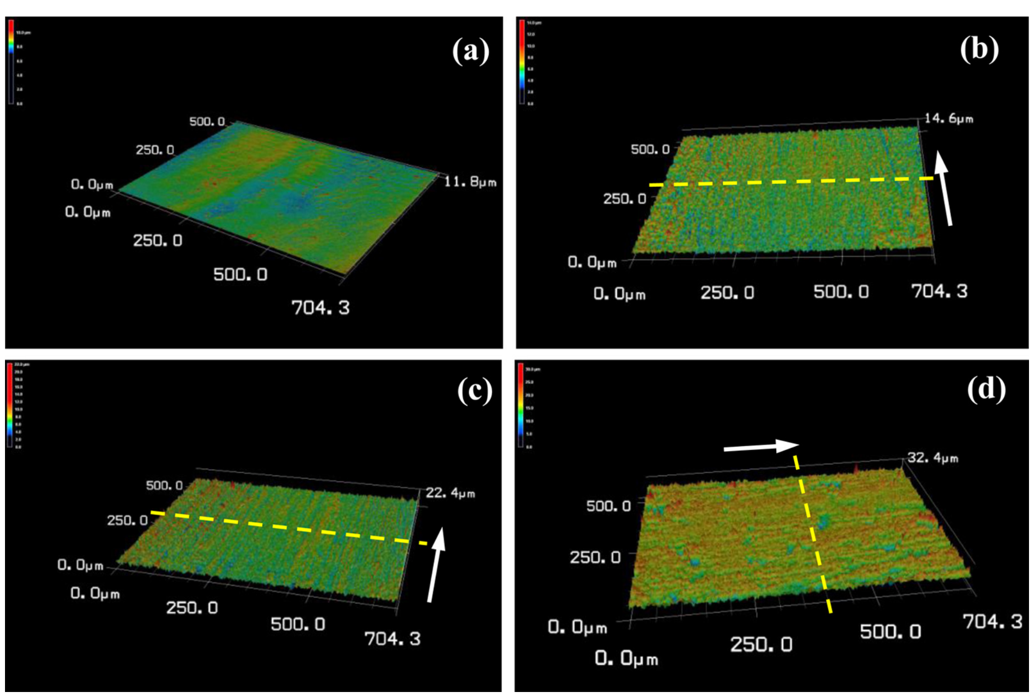

Fig. 1. The 3D profiles of the aluminum alloy surface after sandpapering with different grits size: (a) 3000 mesh; (b) 1500 mesh; (c) 600 mesh; (d) 240 mesh.