Optics and Laser Technology 102 (2018) 25–31

Contents lists available at ScienceDirect

Optics and Laser Technology

journal homepage: www.elsevier.com/locate/optlastec

Full length article

Controllable superhydrophobic aluminum surfaces with tunable adhesion fabricated by femtosecond laser

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ARTICLE INFO

Article history:
Received 22 June 2017
Received in revised form 28 August 2017
Accepted 13 December 2017

Keywords:
Aluminum
Superhydrophobic surfaces
Tunable adhesion
Femtosecond laser

ABSTRACT

In this study, a facile and detailed strategy to fabricate superhydrophobic aluminum surfaces with controllable adhesion by femtosecond laser ablation is presented. The influences of key femtosecond laser processing parameters including the scanning speed, laser power and interval on the wetting properties of the laser-ablated surfaces are investigated. It is demonstrated that the adhesion between water and superhydrophobic surface can be effectively tuned from extremely low adhesion to high adhesion by adjusting laser processing parameters. At the same time, the mechanism is discussed for the changes of the wetting behaviors of the laser-ablated surfaces. These superhydrophobic surfaces with tunable adhesion have many potential applications, such as self-cleaning surface, oil–water separation, anti-icing surface and liquid transportation.

1. Introduction

Superhydrophobic surfaces with an apparent water contact angle (WCA) above 150° are fairly common in the nature. The leaves of certain plants, such as lotus, exhibit extreme water-repellent because the microscopic structures of their surfaces provide them with extremely low adhesion, known as 'lotus effect' [1]. This kind of surface allows water easily roll off and take away dust particles on the surface. Comparatively, the petals of rose, with high adhesion to water, can tightly grasp water droplets even when the surface is put upside down, which is called 'petal effect' [2].

In the past few years, superhydrophobic surfaces have attracted extensive interests due to their potential applications, such as self-cleaning surface, oil–water separation, anti-icing surface and liquid transportation [3–8]. To achieve these functions, it is critical to control the adhesion of the surface. Generally, different surface microstructures, which affect the wetting states of water droplets on the surfaces, play a significant role in regulating adhesions on the superhydrophobic surfaces [2]. Nowadays, various methods have been applied so far to fabricate a variety of hierarchical structures, such as the colloidal template technique, immersion method and electrochemical machining [9–14]. Xu et al. fabricated multi-functional Al surface which showed stable superamphiphobicity, anti-corrosion, and self-cleaning properties [15]. But the process was a little complicated and required a long processing time. In 2015, Yu et al. constructed the submillimeter-scale V-shaped groove arrays on the 5083 Al alloy substrates by the high speed electrical discharge machining technology [16]. After a solution immersion, the structures presented good superhydrophobicity and low adhesion, but the adhesive property could not be regulated on large scale. However, among these proposed methods, it is difficult to control the structures precisely and regulate the adhesion. Besides, some methods are sophisticated and hazardous for the environments.

Femtosecond (fs) laser micromachining is an effective technique to create micro-structures on surfaces for industrial applications [17–22]. And the structures can be easily regulated by adjusting the laser processing parameters, such as laser power, laser scanning speed and scanning overlap. Recently, the wettability of some laser-patterned surfaces has been reported [23–29]. However, most of these works only focused on the superhydrophobicity of surfaces. Little is known about the effects of different fs laser parameters on the surface water adhesion. Only one paper just demonstrated how the scanning speed affected the adhesion [30].

Due to their superior mechanical properties, Al and its alloys are widely used in automotive, aerospace, aviation, shipbuilding and construction industries. Superhydrophobic Al surfaces can be simply fabricated, but the methods for adjusting adhesion and superhydrophobicity on the Al surfaces are few. In this study, the effect of laser power, scanning speed and scanning interval on the fs laser irradiated Al surface structures and surface wetting behaviors are

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https://doi.org/10.1016/j.optlastec.2017.12.024
0030-3992/

investigated. Also, the influence of different laser parameters on the surface water adhesions has been demonstrated. Different hierarchical structures consisting of micro/nano-scale features are fabricated by simply adjusting the laser processing parameters, which lead to different surface wetting abilities. The present paper is sub-divided into two parts. In the first part, fs laser is applied with a wide range of laser power, scanning speed and interval to investigate their effects on the generated structures on the Al surface. In the second part, the influence of surface morphology on the surface wettability and the high-adhesive and low-adhesive superhydrophobic surfaces for on-demand droplet transportation are studied.

2. Materials and methods

The commercial flat Al (30 mm × 2 mm × 1 mm) was mechanical polished and cleaned with deionized water, acetone and anhydrous ethanol in an ultra-sonic bath before laser treatment.

The as-prepared samples were irradiated with a linearly polarized fs laser (Pharos from Light Conversion) with a wavelength of 1030 nm, repetition rate of 75 kHz, and pulse width 1000 fs. The output laser power was adjusted from 1000 mW to 10,000 mW. A two mirror galvanometric scanner (Scanlab, Germany) with an F-Theta objective lens (f = 100 mm) was used and scanned the laser beam in *x-y* direction. The focused diameter of the Gaussian-profile laser at $1/e^2$ of its maximum intensity was approximately 30 μm. The laser scanning was performed line-by-line in the horizontal direction (*x* direction) and then in the vertical direction (*y* direction). The interval of adjacent laser scanning lines was changed from 10 μm to 200 μm, which mean there were two conditions including overlap and no overlap. In the experiments, we changed the scanning speed of the laser beam from 50 to 1000 mm/s.

The residual debris on the laser-ablated samples were removed by being cleaned ultrasonically with ethanol and dried in air. Then the samples were immersed into a 0.015 mol/L aqueous PFOA

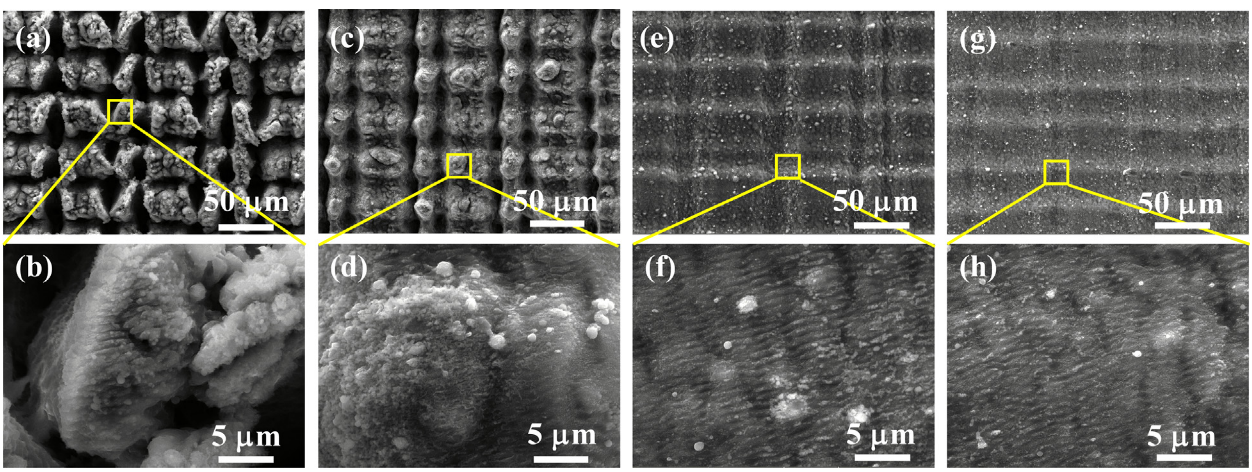

Fig. 1. (a–h) SEM images of the Al surfaces' structures by fs laser at different scanning speeds: (a, b) 50 mm/s, (c, d) 100 mm/s, (e, f) 200 mm/s and (g, h) 400 mm/s. The laser power is 8 W and scanning interval 50 μm.

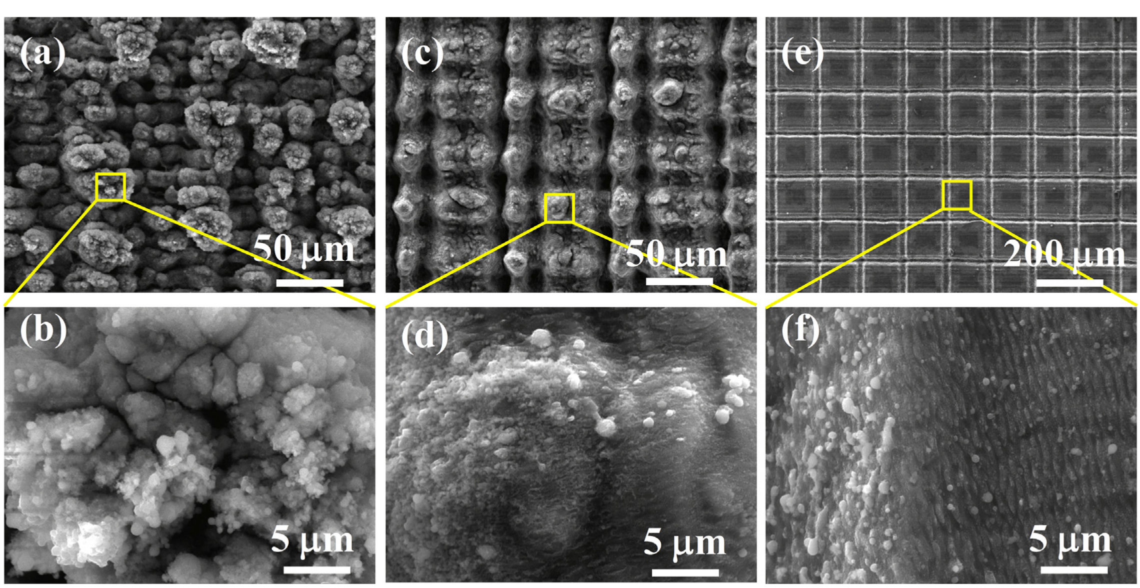

Fig. 2. (a–f) Scanning interval dependence of SEM images of the Al surfaces structures by fs laser: (a, b) 10 μm; (c, d) 50 μm; (e, f) 200 μm. The laser power is 8 W, and scanning speeds 100 mm/s.