Effect of Nanosecond Laser Treatment Parameters on Surface Wettability Behaviour of Pure Aluminium

Jian GUO¹, Xiaolei MA¹, Xuekang SI¹, Zeng YANG¹, Jingnan ZHAO¹,*

¹Mechanical Engineering College, Tianjin University of Science and Technology, Tianjin, 300222, China

Corresponding author: jingnanzhao@tust.edu.cn

Abstract. In this study, a method of preparing stable superhydrophilic surface on aluminum plate by nanosecond laser is presented. The influences of different laser processing parameters on the wettability of aluminum plate and the effect of preservation temperature on the conversion rate of aluminum plate from superhydrophilic to superhydrophobic after laser ablation were studied. It is demonstrated that the microstructure formed by different laser processing parameters has certain influence on the hydrophilic property of aluminum plate, such as the lower the scanning interval and scanning speed, the easier it is to form a superhydrophilic surface. In addition, the storage temperature has a significant effect on the change of surface contact angle with time. The samples stored in the average temperature of 0°C in the atmospheric environment have an average contact angle of 18.7 ° in 60 day after laser treatment, which has always maintained a good hydrophilicity. However, the samples heated 3 hours in the temperature of 150 °C appear the hydrophobicity with an average contact angle of 156.3 °. The mechanism of wettability transition was expounded, and a method to maintain the superhydrophilic durability of metal surface was proposed in this paper.

1. Introduction

In recent years, new properties have been designed on the surface of materials to provide special wettability, such as superhydrophilic and superhydrophobic properties. Wettability can be measured by water droplet contact angle (CA). CA is the angle between the surface of the liquid and the outline of the contact surface (solid surface typically) [1]. When the CA tends to extreme, two kinds of extreme surface are produced super-hydrophilic surface (CA value less 10°) and super hydrophobic surface (CA value over 150°)[1-5]. Hydrophilic materials have potential for use in environmental purification, outdoor protection, medical and health, agriculture, food packaging and other fields [6-8]. Laser as an effective method could fabricate micro/nano structures directly on the surface of many materials and to control the size of micro/nano structure accurately [9-12] Some recent studies on the effect of laser on the wettability of metal surfaces have been reported [9-14]. However, most of these studies focus on the study of surface superhydrophobicity, and there are few independent descriptions of superhydrophilicity.

In this paper, a nanosecond laser method for the preparation of long-term superhydrophilic aluminum plates is presented. The influence of laser parameters on the surface structure and hydrophilicity of aluminum plate was studied. Through the simple adjustment of laser processing parameters, different micro/nano structures can be obtained, so as to produce different hydrophilic effect, and explore the effect of preservation temperature on the long-term retention of aluminum plate superhydrophilic.
2. Experiment
The material used in this study was Aluminum substrate with thickness of 0.5 mm. The aluminum plate was cut into 10 cm×10 cm square, followed by acetone and ultrasonic cleaning in deionized water for 10 min to remove impurities and oil stains on the surface of the aluminum plate.
An nanosecond laser (HANS laser EP-20-SHG) was employed to conduct the experiments with a laser power of 8 W, wavelength of 532nm, a spot size of 20 μm, a focusing focal length of 224mm, a beam mass of M2<1.4, and a pulse repetition frequency of 10-200KHz. The output of the laser wavelength of 532 nm, repetition frequency of 20 KHz, focusing spot diameter for ∅20 μm. The laser texturing pattern at well-controlled size and laser processing parameters were designed via the graphic interface of nanosecond laser control software. In the process of experiment, (line-by-line in both horizontal and vertical directions with equivalent distances between adjacent scanning lines) were used respectively to investigate the effects of different micro/nano structures on surface hydrophilicity, as shown in Figure 1.

![Figure 1. Grid pattern scanning.](image)

3. Results and Discussion
3.1 Surface Analysis
The SEM image of aluminum plate treated by nanosecond laser shows that the change of surface morphology is closely related to laser parameters, such as scanning speed and the scanning interval. The scanning area of each parameter is 10×10 mm². The scanning speed V varies from 100 mm/s to 1900mm/s, and the scanning interval from 0.005 mm to 0.02 mm.

In the process of laser scanning, different micro/nano structure were formed on the machining surface by changing the scanning speed V and scanning interval h. The scanning area of each parameter is 10×10 mm². The scanning speed V varies from 100 mm/s to 1900mm/s, and the scanning interval from 0.005 mm to 0.02 mm.

After laser fabricated, the surface structure was observed by microscope and field-emission scanning electron microscopy. The surface chemistry was analyzed by X-ray spectrometer. In order to identify the change of sample’s wettability, CA tests were taken before and after the laser scanning. The Zhongchen JC2000DM precision automatic CA measuring instrument was used in this study. The CA was measured in an environment with temperature of 22.5 °C and humidity of 47% to 50%. A 25 μl deionized water droplet was dropped to the surface of a sample, then through droplet images to measure the CAs.

3.2 Surface Analysis
The SEM image of aluminum plate treated by nanosecond laser shows that the change of surface morphology is closely related to laser parameters, such as scanning speed and the scanning interval. The scanning interval is 0.005 mm, and the scanning speed is 100mm/s, forming the micro/nano structure, as shown in Figure 2.(a), typical micro/nano dual structure and columnar convex structure can be observed. The size distribution of these columnar structures is not uniform, because of the low scanning speed and scanning interval laser ablation is serious, the material in the recrystallization process is easy to form irregular columnar structure. With the increase of the scanning speed and scanning interval, the density of this columnar convex structure decreases, and nano-scaled ripples gradually appear, forming periodic square and presenting a uniform distribution as shown in the Figure 2.(b). In the enlarged image of a pair of columnar convex structures, we can observe a large number of micro/nano particles randomly distributed on them, as shown in the Figure.2(c). The size and shape distribution of these columnar bulges depend largely on the scanning speed and spacing of the laser.
In order to largely illustrate the relationship between the laser parameters and the surface microstructure, the morphology of the sample was tested, and the three-dimensional contour map of the surface structure was obtained, as shown in Figure 2.(d). The Figure shows a typical three-dimensional outline of the surface, from which the columnar convex structure and nano-scaled ripples can be intuitively observed, and the period of ripple is around 60–70 μm, the surface roughness value is 10.57 μm, with the decrease of scanning speed and scanning interval, the surface roughness value increases. Therefore, the morphology of the surface can be tuned by simply adjusting the scanning speed.

3.2. CA Measurement

The effect of laser texture on the wettability of aluminum plate was studied by measuring the static CA of water drop on the surface of aluminum plate after laser ablation. As shown in Figure 3a, the surface texture CA changes formed by different laser ablation parameters, and each data point presents the average value of three measurements, that is, the CA value of water droplets on aluminum plate. The data in the Figure reflect the relationship between CA on aluminum plate surface and scanning interval and scanning speed. From the perspective of scanning speed, when the scanning interval is constant, the CA on the sample surface increases with the increase of scanning speed. Under the condition of constant scanning speed, CA on the sample surface increases with the increase of scanning interval. When the scanning speed is less than 1000 mm/s all the surface CA is less than 10 °, are characterized by super hydrophilicity. When the scanning interval is small, the CA on the surface of the sample is less affected by the change of scanning speed.

The wettability changes caused by laser treatment were analyzed by comparing the raw aluminum plate with the laser ablation aluminum sample. The hydrophilic surface of the initial polished...
aluminum plate is 82.7. After laser ablation, CA values of all samples were less than 30.8°, showing hydrophilic behavior. The surface hydrophilicity formed by different laser ablation parameters is also different. In this paper, the wenzel model [15] is considered to explain the behavior of water droplets on rough surfaces. In the Wenzel model \( \cos \theta_W = r \cos \theta_e \). The equation shows that the roughness effect amplifies the inherent wettability of the matrix material. Therefore, if the surface of the original aluminum plate is hydrophilic, the surface of the aluminum plate with a certain roughness value after laser ablation will be shown as super hydrophilic, and the microstructure formed on the surface of aluminum plate by grid mode scanning has small spacing and uniform distribution, which is more conducive to the diffusion of water droplets in all directions. In addition, the laser ablation of the aluminum plate surface must have alumina generation. EDS test results O 2 35.6% and Al is 64.4%, and also prove that Al2O3 is formed on the aluminum surface by laser ablation, as shown in Figure 3.(b). Al2O3 itself has polar bonds, has large surface energy, is a hydrophilic substance, commonly used in industry as desiccant. The presence of Al2O3 promotes the surface hydrophilic effect of aluminum plates. Therefore, the formation of hydrophilic nanostructures and hydrophilic substances can well explain the mechanism for the change in wettability to a super-hydrophilic state of aluminum plate after laser ablation.

Figure 3. (a) CA evolution of the laser ablation aluminum surfaces about different laser processing parameters. (b) EDS results for processed aluminum surface

| Storage Temperature (°C) | CA(°) | Storage Time | CA(°) |
|--------------------------|-------|--------------|-------|
| 0                        | 0     | 60day        | 18.7  |
| 50                       | 0     | 24h          | 152   |
| 150                      | 0     | 3h           | 156.3 |

In order to explore the influence of temperature on the CA of aluminum plate surface, the samples after laser ablation (Scanning interval 0.005mm, scanning speeds 100mm/s) were storage in different temperature environments, and the changes in the CA were observed after a period of time, as shown in table 1. Stored in the average temperature of 0°C in the atmospheric environment sample CA was only 18.7° in 60 day after, has always maintained a good hydrophilicity. The stared in an oven at 50°C for 24 hour, CA of 152°, characterized by super hydrophobic. When the storage temperature is 150 degrees Celsius, need only 3 hours CA is 156.3°, characterized by super hydrophobic. Therefore, the preservation temperature has a great impact on the wettability of aluminum plate. It has been reported that the aluminum plate after laser ablation storage at room temperature in the atmospheric environment in the CA is about 30 days up to 150°, super hydrophilic surface into a super hydrophobic within 30 days [9]. Chi-vinh Ngo et al [16] proposed that the laser ablated aluminum
plate could rapidly change from superhydrophilic to superhydrophobic after simple heat treatment. It is found that the adsorption of organic matter by oxide is accelerated during heat treatment. After heat treatment, the aluminum plate surface appears to strengthen hydrophobic groups, the surface becomes super hydrophobic. Therefore, in a certain temperature range, with the increase of temperature, the adsorption of oxide on organic matter in the air will accelerate, resulting in a rapid transition from super hydrophilic aluminum plate to superhydrophobic. Conversely, the low temperature environment can effectively inhibit the adsorption of organic compounds on the surface of aluminum plate by oxides. In order to maintain the superhydrophilic durability of metal surface, an effective method is proposed.

4. Conclusion
To sum up, the nanosecond laser is used to prepare the super-hydrophilic surface on the aluminum plate, so that the processed aluminum plate surface immediately has the super-hydrophilic surface without any post-treatment. The relationship between sample surface hydrophilicity and laser processing parameters was studied. The optimal laser processing parameters were 0.005 mm scanning interval and 100 mm/s scanning speed. In addition, the storage temperature was explored in this study by observing the wettability of the sample surface with the changing of the preservation temperature. It is found that the transition time from superhydrophilic to superhydrophobic decreases with the increase of storage temperature in a certain range (0-150 °C), and the transition takes place within a few hours from the original dozens of days to the present. Through this work, we can learn more about the influence of laser processing parameters on the wettability of aluminum plates, as well as the influence of storage temperature in atmospheric environment on the change of surface CA with time.

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