Investigation on the Effect of Laser Surface Texturing on the Wettability of AISI 316L Stainless Steel

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Abstract

Surface wettability is a specific feature of workpiece surface, where a water droplet is of the high tendency for adhering to or repelling the surface. This is generally referred to hydrophilic and hydrophobic properties. Lasers have widely been used to create a particular micro-structure/texture on the work surface to introduce a desired contact angle of water droplet which is an indicator of wettability. To enhance a better understanding of laser texturing process toward the improvement of surface wettability, this study investigates the effects of major laser parameters on the contact angle of water droplet and morphology of laser-textured surface. AISI 316L stainless steel was used as a sample and its surface was modified by a nanosecond pulse laser. The results revealed that the laser-textured surface exhibited the hydrophilic and rough surface when using high laser power together with long laser-material. In addition, the point-patterned surface caused a larger contact angle than the line pattern while the largest contact angle was 96.734° which will happen whenever the laser power of 4 W and irradiating duration of 3.1 ms were applied. The relationships between the process parameters and surface characteristics presented in this study could be an essential guideline for controlling and improving the surface wettability by the laser texturing process.

Keywords: *Laser, Texturing, Wettability, Stainless Steel, Surface*

1. Introduction

Wettability is a characteristic of liquid that adheres to a solid surface (Pou et al., 2019) and the liquid is generally water. The degree of wettability is quantified by a contact angle between a water droplet and the solid surface. When the contact angle is less than 90°, the surface is considered to possess the hydrophilic property. The surface turns to be hydrophobic when the contact angle is greater than 90°. If the angle is greater than 150°, the surface can be called super-hydrophobic (Atthi et al., 2010). The hydrophilic surface is generally attained on a smooth surface and it can be explained by Young's model (Romano et al., 2019). The hydrophobic surface is relatively rougher than the hydrophilic surface, and Wenzel's and Cassie-Baxter's models are employed to calculate the contact angle (Romano et al., 2019.; Chunhong et al., 2013.; Cai et al., 2018).

There are several methods to prepare the hydrophobic/hydrophilic surface such as surface coating (Sooksaen et al., 2011; Changsiriporn et al., 2017), deep etching (Atthi et al., 2010), electrochemical deposition (Wu et al., 2009) and laser surface texturing (Cai et al., 2018) processes. Among these techniques, the laser texturing process offers a faster processing rate than other processes. With the use of short pulse lasers such as Pico- or femtosecond pulse lasers, the textured surface is of high surface quality with low thermal damage (Grabowski et al., 2018; Ta et al., 2016). However, the high photon cost of these lasers makes them uneconomical for commercial uses. Nanosecond pulse lasers are more commonly applied for materials processing including the texturing process (Li et al., 2019). This type of laser can be used to create the hydrophilic and hydrophobic surfaces on AISI304 stainless steel. Similarly, when nanosecond pulse laser was applied to alter the wettability of AISI 316L stainless steel surface (Cai et al., 2018), they found that the use of proper spacing distance between the laser-ablated structures can maximize the contact angle of the textured surface. By using a nanosecond pulse laser to perform the surface texturing on copper and brass, and the textured surface exhibits the hydrophilicity at the beginning and gradually converts to a stable hydrophobic surface after a certain period of time (Jagdheesh et al., 2019). At the same time, performing a post-vacuum process after the laser surface texturing of titanium alloy, the obtained surface may become ultrahydrophobic with the contact angle of 180° in 120 min (Jagdheesh et al., 2019). In addition to the contact angle, (Duong et al., 2015.; Bizi-bandoki et al., 2013) and (Ma et al., 2013) noted that roughness of the laser-textured surface typically increases when laser energy applied to the process. The change of surface roughness is crucial in the modification process of surface wettability with a controlled roughness. Thus, many studies on the preparation of hydrophilic/hydrophobic surface concern with both the contact angle and the roughness of laser-textured surface.

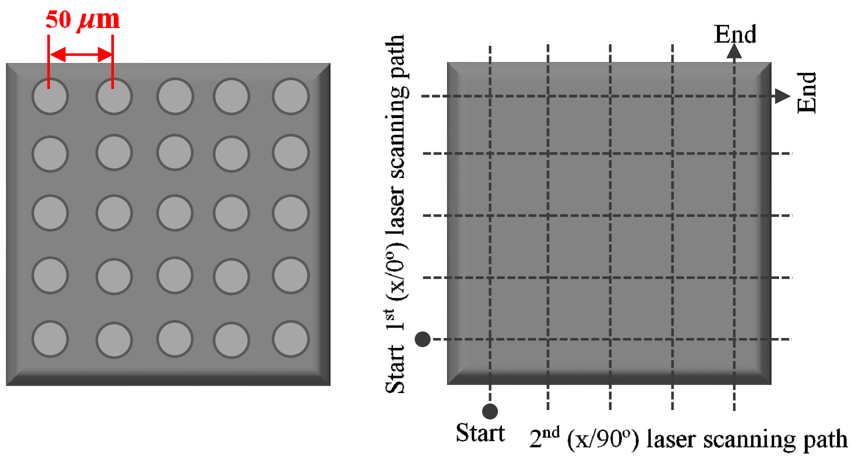
Based on the literature review above, there are many parameters involving in the laser surface texturing process and some contributes a lot to the change of contact angle so as the formation of hydrophilic/hydrophobic surface. To elevate insight knowledge of the laser texturing process toward the modification of surface wettability, this paper aims to investigate the influence of laser power, scan speed/laser-material interaction time and scan pattern on the contact angle and roughness of the textured surface. Stainless steel grade 316L was employed as a specimen in this study because it has extensively been used in medical and pharmaceutical applications, where the surface wettability of equipment used in these areas is relevant to the flowability and cleaning of liquid on the work surface. The findings of this study could tackle a better understanding of laser texturing process on the modification of surface wettability for stainless steel and other metals.

2. Objectives

1. To investigate the influence of laser texturing parameters on the wettability of 316L stainless steel surface.
2. To understand the effects of processing parameters on the physical and metallurgical changes on the laser-textured surface and subsurface of 316L stainless steel.
3. To determine an optimum condition for producing a desired level of surface wettability with minimum damage.

3. Materials and Methods

Nanosecond pulse laser (IPG YLP-V2-1-100, Germany) emitting a wavelength of 1064 nm was used for texturing the surface of AISI316L stainless steel. The average surface roughness (R_a) of as-received workpiece was 0.275 µm. The laser pulse duration and pulse repetition rate were kept constant at 100 ns and 100 kHz, respectively. A focused laser beam with a diameter of 37.66 µm was positioned at the top workpiece surface for all conditions tested in this study. Five levels of average laser power ranging from 4 to 20 W were considered in this study. Two texturing patterns namely line and point with spacing of 50 µm were examined as shown in Figure 1. Four levels of laser scan speed for making the line pattern and four levels of irradiating duration for creating the point pattern were tested in the experiment, and its values are given in Table 1. A 2-µl water droplet was dropped on each laser-textured surface, where the contact angle of the droplet was measured under the backlight to determine the surface wettability. The average surface roughness (R_a) of work samples was also measured in this study. The measurements were performed three times and their average was taken as final reading.



(a) (b)

Figure 1 Laser texturing patterns applied in this study: (a) point; (b) line

Table 1 Process parameters examined in this study

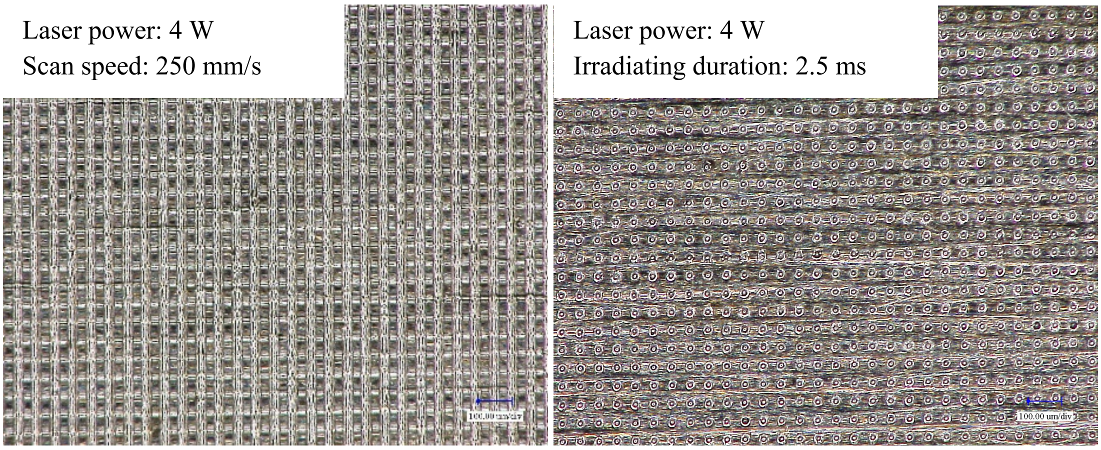
Laser processing parameter	Line pattern	Point pattern
Average laser power [W]	4, 8, 12, 16, 20	4, 8, 12, 16, 20
Scan speed [mm/s]	100, 150, 200, 250	
Irradiating duration [ms]		2.5, 3.1, 4.2, 6.3

4. Results and Discussion

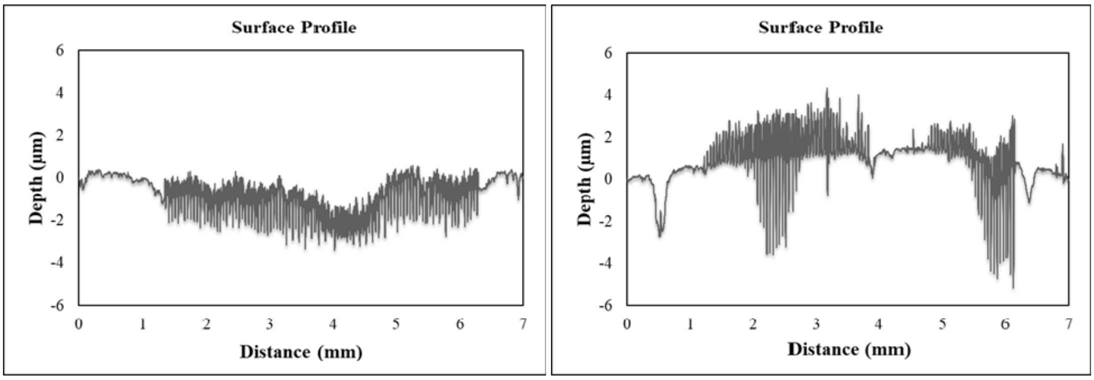
4.1 Surface morphology and roughness

Examples of laser-textured surface morphology associated with the line and point patterns are shown in Figure 2(a) and (b), respectively. The line pattern has two crossing lines that are perpendicular to each other. With the application of laser power and scan speed in this study, there were grooves created on the workpiece surface accompanied with the spacing distance of 50 μm as per the marking pattern. An array of micro holes was produced when applying the point pattern as presented in Figure 2(b). The distance between holes was also 50 μm and the dimensions of hole were subject to the laser power and irradiating duration. Since the laser-irradiated region was undergone phase transformations and some molten material was pushed away from the heating zone during the ablation, the groove and hole edges had thus an agglomeration of recast depositing around them as shown in Figure 2 (c) and (d).

The average roughness (R_a) of laser-textured surface was measured by the profilometer, and the obtained R_a under the different processing conditions is presented in Figure 3. Comparing to the initial work surface having the R_a of 0.275 μm, the textured surface obtained from all tested conditions in this study was rougher than the original one. The maximum R_a was around 10 μm while using the laser power of 20 W. In the light of the results, the augmentation of laser power resulted in the increased the roughness for both line- and point-patterned texturing. As a consequence of the increased laser power, it ablates large grooves and holes on the work surface, which amplifies the roughness. The use of high scan speed for line texturing was found to provide a rougher surface than the slow speed. The high scan speed is expected to introduce short laser-material interaction time and in turn causes the rapid solidification of molten material rather than allows it to flow back into the groove. The almost instant solidification of molten material results in a significant protrusion of recast along the groove edges, thus increasing the surface roughness. Regards Figure 3(b), the use of long irradiating duration of drilling each hole in the point-patterned texturing increases the R_a. This is because a deeper hole is produced under a longer drilling time, so that the work surface turns to be rougher.

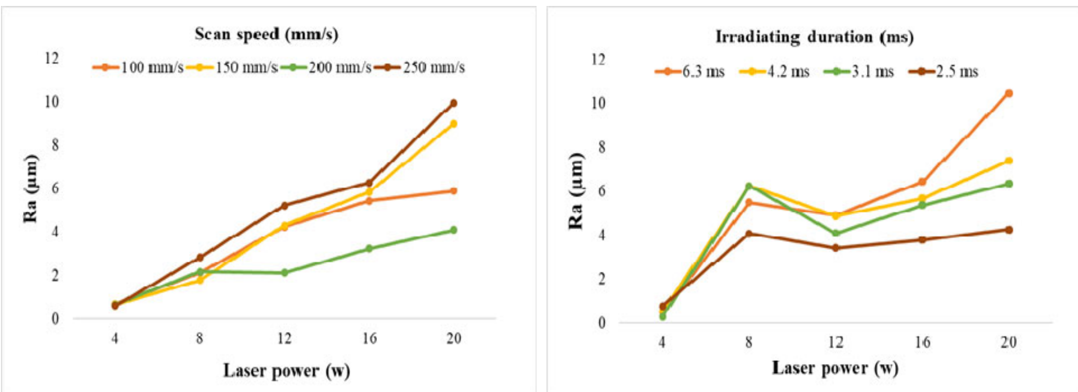


(a) (b)



(c) (d)

Figure 2 Surface morphology and profile of AISI 316L stainless steel after (a, c) line and (b, d) point texturing



(a) (b)

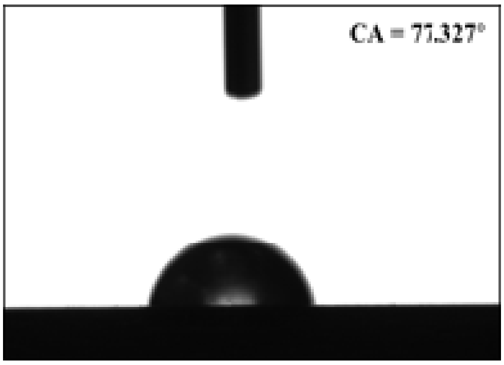
Figure 3 Effect of laser power and scan speed on surface roughness when texturing the (a) line and (b) point patterns

4.2 Surface wettability

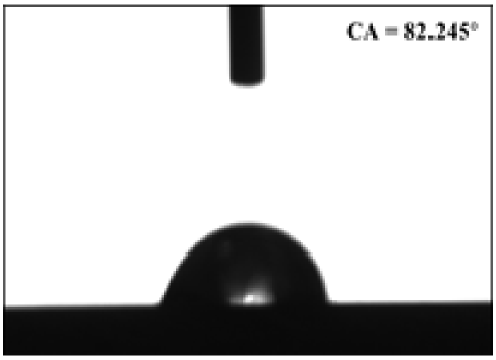
The wettability of laser-textured surface was quantified through the contact angle between the work surface and water droplet. The contact angle of as-received work surface was 73.45 degrees. However, the angle is reduced to zero when the stainless-steel surface was textured by the laser power of equal or greater than 12 W associated with the line pattern as shown in Figure 4 and 5(a). Such surface is considered to be superhydrophilic, and it was obtained when high laser power and slow scan speed were used. According to a study of (Yang et al., 2019) the metal surface is subjected to an oxidation reaction during the laser texturing process. The oxidized metal surface is of high free surface energy which therefore promotes the surface polarity as well as the hydrophilicity. As per Figure 5, the point-patterned surface is likely to have a larger contact angle than the line pattern. In other words, the surface morphology of point pattern provided less hydrophilic state compared to the line pattern. The effect of laser power and irradiating duration on the contact angle of point-textured surface plotted in Figure 5(b) was found to be similar to the line pattern results (Figure 5(a)). With the higher laser power and the longer irradiating time, the lower contact angle was achieved. Regarding the results, the largest contact angle was 96.734° when the laser power of 4 W and irradiating duration of 3.1 ms were used. This is considered to be the hydrophobic surface as the angle is greater than 90°. Furthermore, the increased contact angle was observable under the power of 12 W when associated with the short irradiating time. It is anticipated that the obtained surface satisfies the Cassie-Baxter state in which air is entrapped in the drilled holes and in turn promotes the heterogeneous wetting condition to the surface.

5. Conclusions

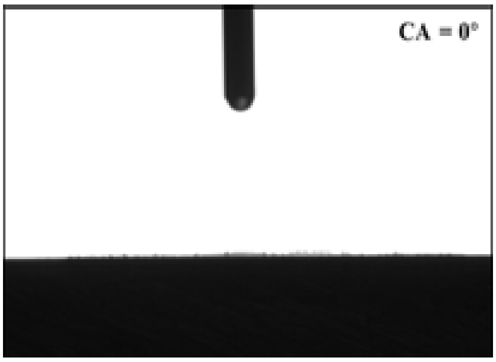
A nanosecond pulse laser was used for texturing AISI 316L stainless steel surface in order to change its wettability. The contact angle of a water droplet on the laser-textured surface was measured to define the level of surface wettability. The effects of laser power, laser-material interaction time and scan pattern on the roughness and contact angle of textured surface were investigated in this study. The laser-textured surface was rough and superhydrophilic whenever high laser power and long laser-material interaction time were applied. In contrast, the hydrophobic surface with the contact angle of 96.734° was made on the work surface when the point pattern was used together with the laser power of 4 W and irradiating duration of 3.1 ms. The findings of this study could be a guideline for controlling and optimizing the laser surface texturing of stainless steel and other metals in order to yield the desired level of surface hydrophobicity/hydrophilicity onward.



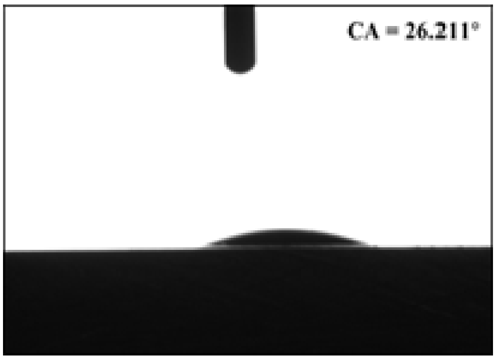
(a) 4W and 250 mm/s (Line)



(b) 4W and 2.5 ms (Point)

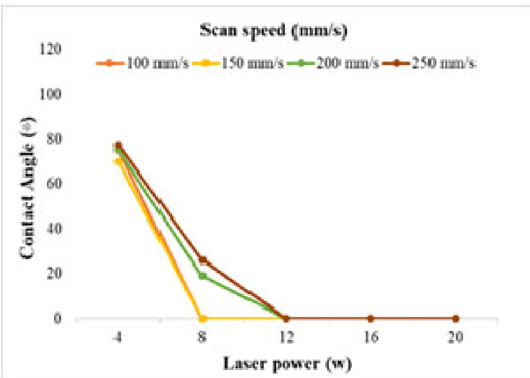


(c) 20W and 250 mm/s (Line)

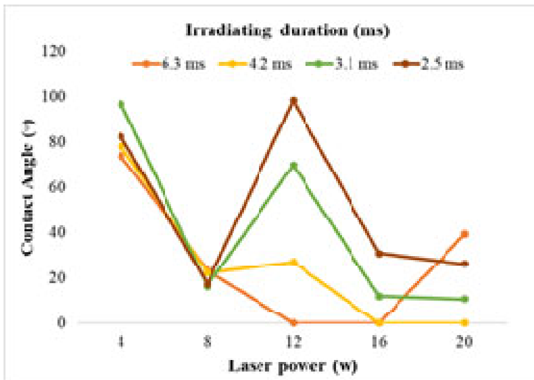


(d) 20W and 2.5 ms (Point)

Figure 4 Water droplet on laser-textured surface produced by using the different processing conditions



(a)



(b)

Figure 5 Effect of laser power and scan speed on contact angle when texturing the (a) line and (b) point patterns

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