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Structural coloration and wettability control of stainless steel by a DLIP process

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Abstract

We present the use of a Direct Laser Interference Patterning (DLIP) setup to modify both optical and wettability properties of stainless steel by a laser surface texturing process. In particular, a two-beams DLIP setup was employed to engrave periodic line-like textures with two different periods on the surface of stainless steel samples. The engraved textures acted as a diffraction grating, allowing the structural coloration of the stainless steel; while achieved a hydrophobic behaviour after applying a post-thermal treatment.

Keywords: DLIP; surface texturing; stainless steel; wettability; optical properties

1. Introduction

Laser surface texturing (LST) has emerged in the last decade as one of the most efficient solutions for surface engineering, allowing the improvement of materials properties as well as providing them with new functionalities. Thus, surface functionalization by LST has become significantly popular for several fields as a means for engineering optical, tribological or biological properties of materials [Xu et al, 2017; Kucynska-Zemla et al, 2020; Soldera et al, 2021].

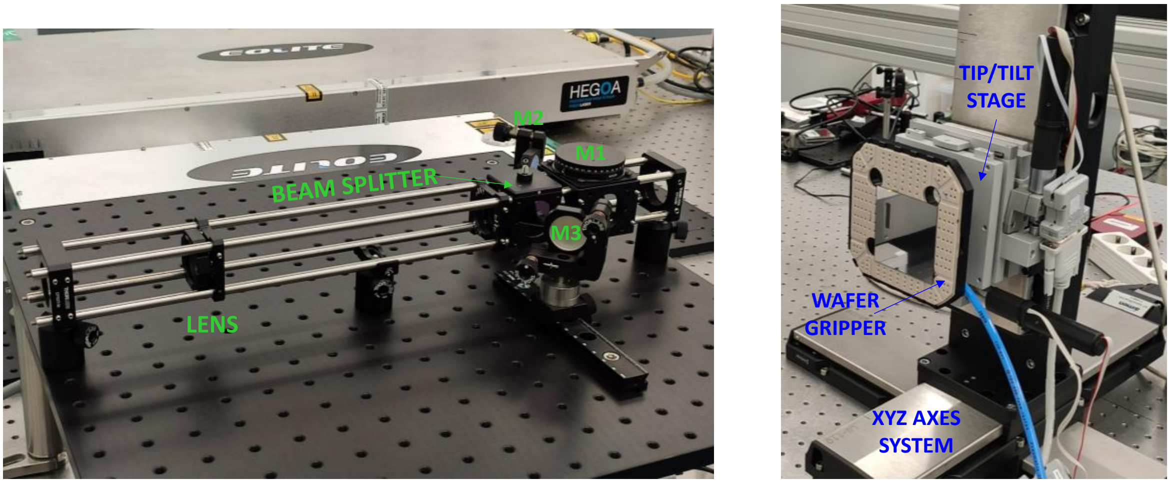
Various techniques have been developed for surface texturing, such as ion beam etching [Marchetto et al, 2008], lithography [Pattersson et al, 2004], hot embossing [Li et al, 2016] or electrochemical machining [Walker et al, 2017], among others. However, LST has gained more and more attention because of its unique advantages: contactless operation, speed, high efficiency, flexibility, environmentally friendly and the capability of generating surface textures with high complexity and accuracy [Singh et al, 2012; Kurell et al, 2005].

Among the LST techniques by a laser ablation process we can distinguish between direct laser writing (DLW) and direct laser interference patterning (DLIP) approaches. In the case of DLW processes, surfaces are commonly scanned with the laser beam by using a galvanometer scanner and structures with a typical resolution from 5 to 100 µm are engraved on various materials [Knowles et al, 2007]. In the case of DLIP, a periodic pattern is created by means of the interference of coherent laser beams [Lasagni et al, 2017]. Thus, periodic structures ranging from 1 to 100 µm can be engraved on the surface of different materials. Comparing with DLW, laser interference allows for fabricating textures with a higher resolution, as well as a higher processing speed [Kunze et al, 2017].

In this paper, we present the use of a DLIP process to engrave line-like pattern textures with a 6 and 3 µm spatial period on stainless steel samples, as a means for engineering both optical and wettability properties of the samples. In Section 2, methods employed for the LST process as well as for the characterization of the engraved textures are presented. Section 3 reports the obtained results and an analysis of them. Finally, section 4 is devoted to conclusions.

2. Methods and materials

A pulsed Ytterbium fiber laser, with picosecond pulses (30 ps) and operating at its fundamental wavelength (1030 nm) has been employed for the surface texturing of stainless steel (304) samples. The DLIP setup is based on a Michelson interferometer, where the laser beam is split into two beams to interfere with each other on the samples surface. Figure 1 shows the part of the DLIP setup corresponding to the interferometer and the configuration employed for the positioning and movement of the samples.



a) b)

Figure 1. Pictures of some parts of DLIP setup: a) interferometer and b) arrangement for the positioning and movement of the samples.

A 50:50 beam splitter was used to split the primary laser beam into two beams, which were then focused on the sample surface through the use of a focusing lens placed at the beginning of the interferometer. Two different lenses, with 750 and 500 mm focal lengths, were used. The position and relative motion of the samples was controlled using a stepper translational XYZ stage, with a 78 nm resolution and a maximum speed of 45 mm/s. Samples were held by a wafer vacuum gripper placed on a tip-tilt stage for the correct positioning of the samples, perfectly perpendicular to the laser beam, and both were attached to the Z axis.

A beam profiling camera was used to observe and optimize the line-like patterns generated with the DLIP setup before texturing the stainless steel samples. Finally, textured areas were characterized in terms of both topographical and functional features. A confocal microscope was employed for analysing the topography of the textures, while an optical tensiometer was used to determine the contact angle of the textured areas.

3. Results and discussion

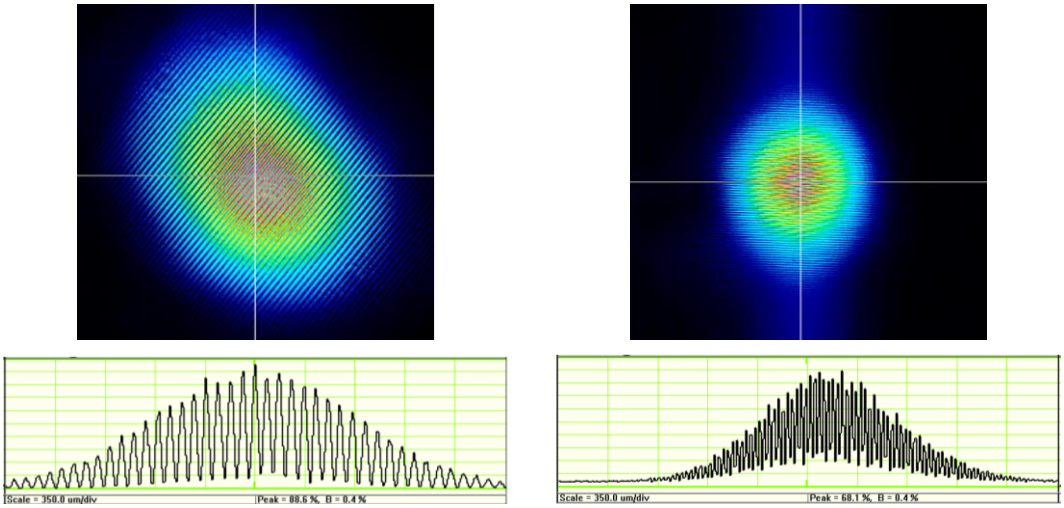
3.1 Laser interference pattern

In the case of a two-beams DLIP setup, a line-like interference pattern is generated and its spatial period (Λ) is given by:

$$\Lambda = \frac{\lambda}{2sin\theta} \tag{1}$$

where λ is the wavelength of the laser, and 2θ is the angle between the interfering laser beams. For a 1030 nm laser beam and a 10° angle between the interfering beams, a line-like pattern with a 6 µm period is obtained; while a 3 µm period is obtained for an interference angle of 20°. By moving mirrors 2 and 3 of our DLIP setup (see Figure 1, elements M2 and M3), both line-like patterns of 6 and 3 µm period were obtained. Figure 2 shows the two interference patterns observed with a beam profiling camera.

a) b)



Interference pixel diameter ~ 275 µm   Interference pixel diameter ~ 180 µm

Figure 2. Intensity profile of the interference pattern obtained with our DLIP setup configured to obtain: a) a 6 µm period pattern and b) a 3 µm period pattern.

A focusing lens of 750 mm focal length was used in the DLIP configuration employed for the 6 µm period interference pattern, obtaining an interference pixel diameter about 275 µm; while a focusing lens of 500 mm focal length was used for the 3 µm period configuration, obtaining a smaller interference pixel with a diameter of approximately 180 µm.

3.2 Surface textures engraved on stainless steel

The interfering beams were focused on the surface of stainless steel samples to engrave line-like textures in 1 x 1 cm^2 areas. A pulse energy between 10 and 25 µJ and a repetition rate of 100 kHz were employed for the LST process, while the samples were moved at a speed between 16 and 22 mm/s. After engraving the line-like pattern by moving the sample in the same direction of the interference pattern, samples were moved a distance equal to a multiple of the pattern's period and the line-like pattern was engraved again. This procedure was repeated until cover an area of 1 x 1 cm^2. Figure 3 shows the 6 and 3 µm period textures engraved on the surface of stainless steel samples by a DLIP process.

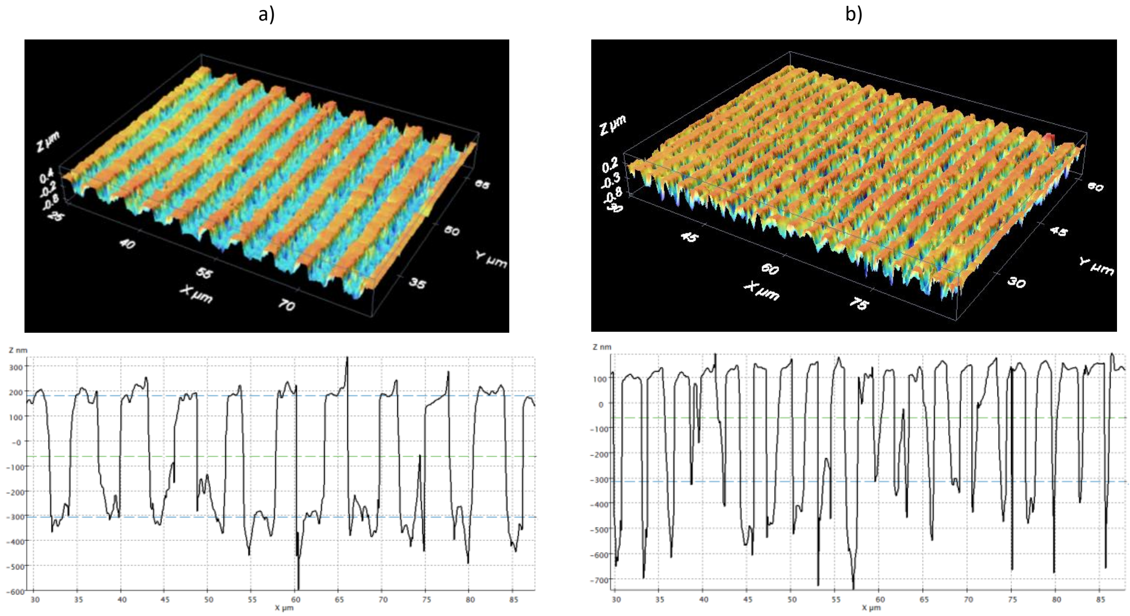
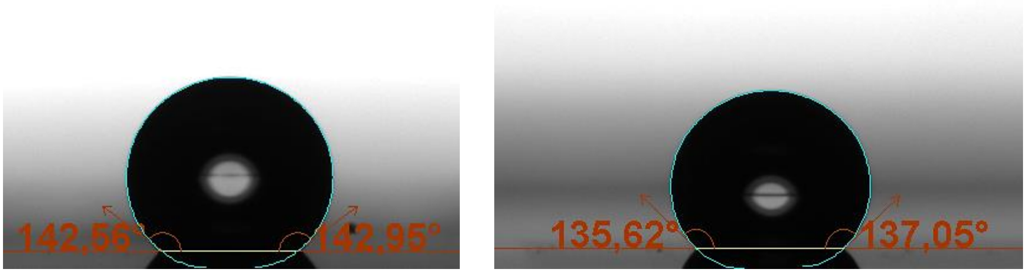


Figure 3. 3D image and 2D profile obtained with the confocal microscope for: a) the surface line-like texture engraved with a 6 µm period interference pattern and b) the line-like texture engraved on the surface of a stainless steel sample with a 3 µm period interference pattern.

As can be seen in Figure 3, both line-line textures presented grooves with a depth of about 0.5 µm, while the width of the grooves changed according to the period of the pattern. As expected, a width of 3 µm was measured for the grooves of the 6 µm period texture and a 1.5 µm width was measured for the grooves of the texture with a 3 µm period.

3.3 Functional properties

Just after applying the LST process, a contact angle lower than 10° was observed for both kind of textures. However, and as it was expected according to the literature about LST of metals [Trdan et al, 2017], the contact angle of the textured surfaces was increasing over time; which means that the wettability of the material evolved towards a hydrophobic behaviour for those textured regions. The transition from hydrophilicity to hydrophobicity of laser surface textures is being widely studied in the literature and different treatments to be applied after the LST process are being investigated to accelerate the transition process [Long et al, 2015; Ngo et al, 2017; Jagdheesh et al, 2017]. We decided to apply one of these treatments to our stainless steel textured samples. Thus, a post-thermal treatment was applied and samples were heated to 100 °C for 6 hours. Figure 4 shows the contact angle measured for the textured areas after applying the thermal treatment.



a) b)

Figure 4. Contact angle measured for the line-like textures engraved on stainless steel with: a) a 6 µm period and b) a 3 µm period.

As can be seen, the surface textured with the 6 µm period pattern achieved a higher contact angle than the surface textured with the 3 µm period pattern. The hydrophobicity of both textures was maintained over time after applying the thermal treatment.

Apart from the wettability control of the stainless steel samples, it was also observed that the LST process allowed the structural coloration of the samples since the engraved textures act as a diffraction grating. Figure 5 shows an example of this phenomenon.

Figure 5. Picture of an AIMEN's logo engraved on the surface of a stainless steel sample by using a 6 µm period laser interference pattern.

4. Conclusions

The use of a two-beams DLIP setup has been investigated for the LST of stainless steel samples with line-like textures. Two different configurations of the DLIP setup, for obtaining a 6 and a 3 µm period laser interference pattern, were arranged.

Line-like textures with both periods of 6 and 3 µm were successfully engraved on the surface of stainless steel samples, allowing the modification of both wettability and optical properties. Textures with the highest period achieved a higher contact angle value after applying a post-thermal treatment. While both kind of line-like textures acted as a diffraction grating, allowing the structural coloration of the stainless steel samples.

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