Effect of Laser Processing Parameters on Surface Texture of Ti6Al4V Alloy

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Abstract. Surface micro-machining was performed on Ti6Al4V alloy sample by nanosecond laser. The micro-morphology, the depth of texture and the chemical composition of melt deposits were analyzed through different techniques including Ultra-Depth Microscopy, SEM and EDS. The single factor method was applied to investigate the influence of different laser parameters on the depth of texture and micro-morphology. The result showed that the depth of texture increased first and decreased with the increase of average power (11-20.9W), the texture depth decreases sharply when the scanning speed increased from 10mm/s to 40mm/s, and the repetition frequency had little effect on the depth of texture. It was possible to select an optimum combination of laser processing parameters that obtain different depths of texture without decreasing the surface quality of texture.

1. Introduction

Ti6Al4V alloy has extensively applied in the aerospace fields due to its excellent mechanical properties, low density and top resistance to corrosion. Geometric figures with certain size and arrangement can improve the tribological performance significantly[1-3]. Thus, the morphology of surface texture has an important influence on the tribological properties of materials. And laser surface texture (LST) is increasingly widely used in surface texture processing because of its high efficiency, and simple operation.

At present, surface micro-texture has been applied successfully in mechanism analysis, tribological application and processing technology. In the material removal mechanism, Zhang et al[4-5]. established the laser ablation model which was based on the theory of temperature field, and studied the influence of laser parameters on the shape and depth of morphology. Besides, more detailed material removal mechanisms corresponding to different parameters were studied by Zhao et al[6]. And it provided a powerful basis for the material removal mechanism. In the application of tribology, Chang et al[7]. used pulsed-laser micro sintering on 45 steel, which demonstrated that laser texture can improve tribological performance through ring-block tests under certain conditions. However, friction reduction performance of surface texture under dry friction cannot be successfully applied in oil-depleted condition due to its complexity. Li et al[8]. reported that surface texture could effectively reduce the friction coefficient because it could collect debris and store lubricants. In addition, surface texture processed by laser was also used to improve tool wear. Zhang et al[9]. had fabricated microtexture on the surface of coated tool successfully, and found that compared with the tool without texturing treatment, the wear condition of the tool after texturing treatment was obviously improved. In the processing technology, Wang et al[10]. used femtosecond laser to fabricate pits on TiC surface,
and analyzed the mechanism of laser and material. Zhao et al[11]. investigated the absorption process of infrared laser by analyzing the relationship between laser parameters and laser absorptivity.

The geometry and topography of the textures were generated by LST, and it corresponds to laser parameters[12-13]. The aim of the study was to determine the influence of laser parameters on the geometry and topography of textures generated by nanosecond pulsed laser ablation on the surfaces of Ti6Al4V alloy. Meanwhile, processing parameters of different depths are available on the premise of guaranteeing certain processing quality, which would lay a foundation for further research on friction and wear test of a textured surface and surface coating modification.

2. Experiment

Table 1. Chemical composition of TC4 alloy (wt%).

|     | Al | V  | Fe | O  | N  | H  | C   | Ti  |
|-----|----|----|----|----|----|----|-----|-----|
|     | 6.1| 4.1| 0.15| 0.09| 0.02| 0.001| 0.01| Bal.

The samples were a commercial Ti6Al4V at the size of 15×5×5mm. The chemical composition of Ti6Al4V alloy was shown in Table 1. They were mechanically polished using a dry grinding on SiC papers of P1200 grade and finally polished with a solution to 50% of colloidal silica gel of 0.04 μm in H2O2. Then, the surfaces were ultrasonically cleaned with deionized water and ethanol. Finally, it dried in air.

Texture was performed using a solid state pulsed Nd: P20QE laser with spot diameter of 7mm, wavelength of 1064nm, pulse width of 126ns, and other parameters were shown in Table 2. The textured diameter was 300μm, the depth of texture was 20-30μm, and the depth of texture \( h_a \) was defined by equation (1) and Figure 1.

\[
h_a = \frac{1}{R} \int_0^R |Z(x)|dx \approx \frac{1}{n} \sum_{i=1}^{n} |Z_i|
\]

Table 2. Laser Processing Parameters.

| Laser parameters | Average power (W) | Repetition rate (kHz) | Scanning speed (mm/s) |
|-------------------|-------------------|----------------------|-----------------------|
| values            | 11-20.9           | 30-60                | 10-40                 |

After fabrication, the treated surfaces were characterized using Ultra-Depth Microscopy with 500×. And the 3D morphology was obtained. In addition, SEM was used to observe the micro-morphology. Finally, the required laser parameters which correspond to separate the depths of texture were required.

3 Result and discussion

3.1 Effect of average power on texture morphology

The texture was obtained at the scanning speed of 10mm/s, the repetition rate of 30kHz, and the average power varied from 11-20.9W. It can be found from Figure 2, the depth of texture increased first and decreased with the increase of average power. This was mainly attributed to the fact that the laser energy density increases with the increase of average power and the surface temperature reached the threshold value of Ti6Al4V alloy gasification. Therefore, the surface material was burned and gasified. At this time, the texture depth increased linearly. However, too much power led to an increase in melt accumulation within the texture, thus the depth of texture decreased to a certain extent.
As shown in Figure 4, there were many melt deposits in texture, which were a crescent-shaped depression. This was mainly due to the laser processing mode caused the burn in a linear way. Laser material removal was carried out by linear scanning with filling lines. At the beginning of processing, the surface material was removed. As time goes on, dust and gases in the laser ablation process attached to the surface of the material, forming a protective layer. It would be removed preferentially when the laser irradiated on the unprocessed surface. Moreover, the accumulation of melt in texture increased with the increase of average power. To further investigate the composition of molten matter. The EDS was studied of the above materials as shown in Figure 4. It can be seen that the melt contained Ti, Al, V, O and C. However, the percentage of O and C were much higher than that of Ti6Al4V (Table 1). It also can be proved that laser produced oxides and carbides during the burning process. They existed in the texture with an irregular form, which not only affected the morphology of the bottom of the seat, but also the processing quality. Therefore, the processing parameters corresponding to better texture morphology were obtained, which were compared with different results. The average power varied from 11-14.3W.

3.2 Effect of scanning speed on texture morphology
One of the most important factors is related to efficiency of material surface processing is scanning speed. The laser parameters were selected as follows: average power was 14.3W, repetition rate was 30kHz, and scanning speed ranged from 10mm/s to 40mm/s. The depths of texture at different scanning speeds were presented in Figure 5. It can be indicated that a sharp downtrend with increasing scanning speed. It was that average power and repetition frequency were constant, resulting in a single constant pulse energy. As the scanning speed increased, the number of pulses generated on the unit line decreased, which led to a reduction in the removal of the material surface due to a reduction in pulse overlap.
Figure 4. The analysis of EDS.

Figure 5. The relationship between $h_a$ and scanning speed.

Figure 6 had shown the micro morphology in different scanning speeds. It can be found that scanning speed had great influence on texture morphology and melt accumulation. The depth of texture at 10mm/s was higher than others, while the degree of melt accumulation was the smallest. When the scanning speed continued to increase, the less surface pulse overlaps the less material removal rate. It was the shallowest depth when the scanning speed was 40mm/s, whereas, there were many melts accumulated in the texture, which affected the processing quality seriously. For scanning speed at a range of 10-20mm/s, the processing quality was better than others.

3.3 Effect of repetition rate on texture morphology

The relation between the depth of texture and repetition rate was indicated in Figure 7. It can be seen that the depth of texture were slightly increased. However, it had less effect on texture depth than other parameters. The reason for this phenomenon was that the adjustable interval of repetition frequency was too small (30-60kHz) to be treated as a fixed value, thus it had little influence on the micro-morphology.

Figure 7. The relationship between $h_a$ and repetition rates.

It can be inferred from Figure 8 that there was a small amount of melt accumulated in the texture. The most frequent melt in texture was 30kHz, meanwhile, it had a poor processing effect due to an uneven bottom. When the repetition rate was 60kHz, the heat-affected area around the texture and the accumulation of melt in the texture decreased, which was due to the decrease of the single pulse
energy produced by the laser. And it was a conclusion that the effect of repetition rates on surface texture was less in comparison to other parameters. The better processing effect was obtained at 60kHz.

4. Conclusion
The depth of texture was positively correlated with average power and negatively correlated with scanning speed. However, excessive power led to depth reduction. Repetition frequency had less effect on surface texture in comparison with average power and scanning speed. The laser parameters corresponding to different values of the depth of texture (20-30μm) were as follows: scanning speeds in 10-20mm/s, repetition rate was 60kHz, and average power varied from 11-17.6W.

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