Optik - International Journal for Light and Electron Optics 174 (2018) 766–775

Contents lists available at ScienceDirect

Optik

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

Original research article

Surface morphology of titanium alloy with monolayer microparticles under different single pulse laser energy

Tong Yanqun[a], Yang Ning[a], Han Kuiguo[a], Yuan Shouqi[b], Zhou Jianzhong[a], Chen Xiaoming[c], Shi Lin[a], Li Wei[b], Ren Xudong[a,*]

[a] Department of Mechanical Engineering, Jiangsu University, Zhenjiang, 212013, PR China
[b] National Research Center of Pumps, Jiangsu University, Zhenjiang, 212013, PR China
[c] Key Laboratory of Research on Hydraulic and Hydro-Power Equipment Surface Engineering Technology of Zhejiang Province, Hangzhou, 310012, PR China

ARTICLE INFO

Keywords:
Titanium alloy
Microparticles
Nanosecond laser
Local field enhancement
Micromachining

ABSTRACT

The surface morphology characteristics of titanium alloy under single pulse energy with local field enhancement effect were studied. The surface morphology of titanium alloy was observed by scanning electron microscope and local field enhancement theory was discussed by the FTDT simulation. The key difficulty of monolayer particles deposition was solved by production of a hydrophilic film and spin coating method. The formation mechanism of the surface morphology was discussed. Our results indicate the surface morphology is related to local field enhancement and the laser parameters including energy, size and distribution of laser spot. By using lower laser fluence than the ablation threshold of titanium alloy, laser cleaning can be obtained. When the microparticles-enhanced laser energy reaches the ablation threshold of titanium alloy surface, micropores whose size between 300 nm and 400 nm are easily obtained. The micropores distribution is related to the shape of laser spot. When the laser energy of laser spot exceeds the ablation threshold, microparticles help to control the shape of hole. The results show that particles can effectively influence the quality of laser processing, which is theory and practical significance on promoting laser processing technique in the application of particles on titanium alloy.

1. Introduction

As a common metal for medical implant, titanium alloy has the characteristics of low modulus of elasticity and high biocompatibility. The surface morphology of titanium alloy plays a decisive role in the survival rate of the implant [1,2]. At present, the researchers mainly get the surface morphology through mechanical polishing [3,4], electrochemical polishing [6,7], shot peening [8,9], acid etching [10–12] and so on. Duan [13] used chemical mechanical polishing to make ultra-precision surface machining of titanium alloy. Xu [14] treated the TC4 titanium alloy with electrochemical polishing and studied the treatment of surface morphology and phase. Han [15] discussed the influence and mechanism of shot peening factors (including residual compressive stress introduction, surface roughness and surface work hardening) on the erosion behavior of Ti6A14V titanium alloy surface. Laser surface modification technology of titanium alloy is a hot topic in recent years.

Laser surface treatment is a novel and efficient method for titanium alloy. Different from the traditional surface treatment

* Corresponding author.
E-mail address: renxd@mail.ujs.edu.cn (R. Xudong).

https://doi.org/10.1016/j.ijleo.2018.08.077
Received 9 April 2018; Received in revised form 21 August 2018; Accepted 22 August 2018
0030-4026/

technology, laser surface treatment technology changes the surface characteristics of the material by interacting with the laser and material, and realizes the surface fabrication of micropore. Laser surface treatment technology has the advantages of small size, good controllability, low energy consumption and good repeatability, which has a broad application prospect and can provide important manufacturing support for the leapfrog development in the fields of Bio Medical, Aerospace and Energy Vehicles. Dubravka [16] studied the temperature distribution of a single and multi pulse laser beam on the surface of Ti6Al4V titanium alloy. Diao [17] made laser cladding on the surface of TC2 titanium alloy, and studied the microstructure, composition, phase composition, hardness and corrosion resistance of the surface before and after laser treatment. Liu [18] and other researchers analyzed the law of surface temperature field of titanium alloy after laser action, and studied the characteristics of surface topography under different laser processing parameters. Man [19] demonstrated the formation of self-organized nanogratings on a titanium surface under the irradiation of a single-beam femtosecond laser. The characteristic size and resolution of laser processing are limited by the diffraction limit of the laser beam. Micro particles can help to produce smaller dimensions. Lu [20] proposed the use of microparticles as a tool to induce laser nano patterning on Si substrates, initially Using 0.5 μm silica particles and wavelength 248 nm KrF excimer laser to make 100 nm small protrusions on the surface of Si. Muenzer [21] also used a laser beam to irradiated on polystyrene particles, making nanometer holes on the glass and silicon substrate. Terakawa [22] reviewed the coupling effect of near field and discussed the highthroughput nanohole fabrication mediated by arrayed nanospheres. SEM image of the silicon surface after femtosecond laser irradiation were observed. But the problem of single-layer arrangement of micro-particles on titanium alloy surface was not solved. The method of microparticles-enhanced laser processing on titanium alloy has potential applications in medical implant.

The laser processing technology based on microparticles can achieve large and controllable surface treatment by the near field principle. The surface morphology was observed by scanning electron microscope and local field enhancement theory was discussed by the FTDT simulation. The diversity of surface morphology of titanium alloy with single layer microparticles under different single pulse laser energy was obtained. The interaction mechanism between particles and titanium alloy surface with Gauss beam was discussed.

2. Experimental setup

2.1. Experimental materials and treatment

TC4 type Ti-6Al-4V titanium alloy are used for this experiment whose conposition are as indicated in Table 1. The deposition of monolayer microparticles requires high surface quality of the substrate. On the one hand, the substrate surface must satisfy the hydrophilic property, and on the other hand, the substrate surface needs to be smooth enough for deposition. In order to solve the difficult problem of microparticles deposition, sample preparation was divided into five steps: (1) The titanium alloy samples after mirror polishing were purchased from suppliers and the surface roughness was about 42 nm. (2) Hydrophilic film preparation: Super wetting agent was used as a hydrophilic medium to make titanium alloy surface hydrophilic. Super wetting agent and distilled water was mixed into hydrophilic reagent. The reagent was dripped to the surface of titanium alloy after uniform ultrasonic mixing, and then rotated and dried by glue homogenizing machine. A hydrophilic film was prepared to facilitate the deposition of microparticles; (3) Put the samples in a dust-free drying box; (4) The particle array was made by spin coating microparticles dispersion. The silica suspension with a diameter of 0.5 μm and a volume fraction of 5 wt% was first placed in the ultrasonic cleaner for 10 min and dispersed. Use a micropipette to take 100 μL each time to be carefully covered with the surface of the hydrophilic titanium alloy. When the liquid become almost as thick as the sphere diameter, there was strong immersion capillary attraction between particles and form arrangements of particles through the deposition, rotation, separation and evaporation of solvents. The process of spin coating was also divided into two steps. Firstly, add the suspension at low speed. Secondly centrifugal evaporate at high speed. Lots of experimental results showed that when the parameters of the homogenizing machine rotate 15 s at low speed 500 rpm, and rotate 50 s at high speed 2000 rpm, the micro-particles on the titanium alloy surface were better laid. Result of particle arrangement is shown in Fig. 1.

2.2. Experimental setup

The schematic diagram of the experimental system is shown in Fig. 2. The sample was placed on a three-dimensional mobile platform. Laser (λ = 1064 nm) was focused on microparticle film through a field mirror (f = 160 mm). The laser beam diameter was 50 μm. The scanning speed of the scanning galvanometer was adjusted to control the distance between the spots. The laser spot intensity was Gaussian distribution and the pulse width was 100 ns.

A scanning electron microscope (SEM S-3400N) and microscope (AxioCSM700) were employed to observe the surface morphology. The mode of laser spot is analyzed by array laser beam analyzer.

Table 1
Composition of Ti6Al4V titanium alloy.

element	Al	V	Fe	O	Si	C	N	H	Other	Ti
component	5.5–6.8	3.5–4.5	0.3	0.2	0.15	0.1	0.05	0.01	0.5	remain