Vacuum 158 (2018) 141–145

Contents lists available at ScienceDirect

Vacuum

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

Short communication

Analysis of microstructure and tensile properties produced by cryogenic laser peening on 2024-T351 aluminum alloy

Jing Li[a,*], Jianzhong Zhou[a,**], Aixin Feng[b,c], Yunjie Sun[a], Yu Huang[a], Xuliang Tian[a], Shu Huang[a], Xiankai Meng[a]

[a] School of Mechanical Engineering, Jiangsu University, Zhenjiang, 212013, PR China
[b] College of Mechanical & Electrical Engineering, Wenzhou University, Wenzhou, 325035, PR China
[c] Institute of Laser and Opto Electronics Manufacturing Wenzhou University, Wenzhou, 325000, PR China

ARTICLE INFO

Keywords:
2024-T351 aluminum alloy
Cryogenic laser peening
Microstructure
Tensile properties

ABSTRACT

The microstructural response and tensile properties on 2024-T351 aluminum alloy specimens induced by cryogenic laser peening were investigated. The microstructure behaviors were characterized by transmission electron microscopic examination and electron backscattered diffraction analysis. Tensile properties tests at room temperature were also performed. The experimental results cleared that compared with room temperature laser peening, cryogenic laser peening can induce higher-density of dislocation and smaller-size grain, while the strength and plasticity of the processed 2024-T351 aluminum alloy were simultaneously increased. The analysis results suggested that the more excellent tensile properties were attributed to the more beneficial microstructural evolution induced by cryogenic laser peening.

1. Introduction

Due to its advantages, such as high strength to weight ratio, resistance to fatigue, and improved corrosion properties, 2024-T351 aluminum alloy has been widely used in the manufacture of high-load mechanical components in the aerospace field [1,2]. Unfortunately, various failure behaviors, such as frictional wear, corrosion, fatigue and fracture, are very likely to occur in the service process with complex loads, resulting in great threats and injuries to the national economy and personal safety [3,4]. Therefore, it is of great practical significance to further enhance the comprehensive mechanical properties of 2024-T351 aluminum alloy.

As a competitive and effective surface strengthening technique, Laser Peening (LP) can effectively produce the beneficial microstructure and compressive residual stress on the surface layer of treated materials, thereby improving their mechanical properties [5–7]. For example, Maozhong Ge et al. [5] analyzed the effects of LP on microstructure and fatigue crack growth rate of AZ31B magnesium alloy. And their research results suggested that LP could induce high compressive residual stress and nanocrystalline layer, which attributed to the decrease of fatigue crack growth rate. Lei Zheng et al. [6] investigated the performance of micro-dent array fabricated by LP on the surface of A304 stainless steel. The experimental results found that the improvement of wear performance of A304 stainless steel may due to the combined effects of improved surface microhardness and the existence of compressive residual stress induced by LP. In addition, Rujian Sun et al. [7] also found that after LP, high density of dislocations and mechanical twins were generated and resulted in the increase of microhardness, a less misorientation grains with weak texture were achieved, as well as residual stresses were modified from tensile to compressive state with a maximum value around 100 MPa. Meanwhile, many studies have also shown that the synergistic effect of cryogenic process and deformation strengthening technique can provide better microstructure and comprehensive mechanical properties for the treated metallic materials [8,9]. Especially, Ye and collaborators [10,11] explored the effects of Cryogenic Laser Peening (CLP) on the microstructure and mechanical properties of a variety of metallic materials. Their research results demonstrated that compared with room temperature laser peening (RT-LP), CLP can induce more beneficial microstructures and play an important role in further heightening the mechanical properties of treated materials.

In the paper, the purpose of our research was to explore the effects of RT-LP and CLP on the microstructure and tensile properties of 2024-T351 aluminum alloy. At the same time, the difference of the

* Corresponding author.
** Corresponding author.
E-mail addresses: ljingvip@sina.cn (J. Li), zhoujz@ujs.edu.cn (J. Zhou).

https://doi.org/10.1016/j.vacuum.2018.09.043
Received 17 July 2018; Received in revised form 20 August 2018; Accepted 21 September 2018
Available online 22 September 2018
0042-207X/

Table 1
Chemical composition of 2024-T351 aluminum alloy used in this study (wt.%).

Element	Cu	Mg	Fe	Si	Mn	Zn	Ti	Cr	Al
(wt%)	3.8–4.9	1.2–1.8	0.5	0.5	0.3–0.9	0.25	0.15	0.10	Bal.

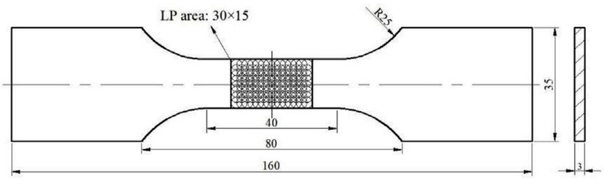

Fig. 1. Dimension and LP area of the specimen used for tensile test at room temperature.

microscopic strengthening mechanism for the enhancement of tensile properties between the processes of RT-LP and CLP was also compared.

2. Experimental procedure

The material used in this study is 2024-T351 aluminum alloy, whose chemical composition is also given in Table 1. The CLP experiments were carried out using a SpitLight 2000 pulsed Nd:YAG solid-state laser with a wavelength of 1064 nm and a pulse width of 8 ns. The spot diameter was 1 mm, and the overlap ratio was 50% as well as the laser energy chosen in this study was 1.6 J. A 120 μm professional aluminum foil was used as the absorbing layer, while a 3 mm thick K9 glass was used as the transparent confining layer. The temperature of the specimens used for CLP treatment was maintained at (−130 ± 2) °C. Electron Backscattered Diffraction (EBSD) analysis was carried out using a Zeiss Sigma 500 Scanning Electron Microscopy (SEM) system. Meanwhile, the microstructure was characterized by a Transmission Electron Microscopy (TEM). An X-ray diffraction with sin2Ψ (X-350 X-ray, produced by Handan stress technologies institute) method was used to measure the Full Width at Half Maximum (FWHM) values on the top surface of the specimens with different treatments. The tensile test at room temperature was performed on a WDW-200G electronic universal testing machine. The load rate selected for this test was 1 mm/min as well as the tensile strain rate was $1.0 \times 10^{-3}\ s^{-1}$. For each treatment, three specimens were selected for tensile test, and the average values of strength and elongation were taken as the final results. And the dimension and LP area of the specimens used for tensile test at room temperature were presented in Fig. 1. After the tensile tests completed, the fracture was also observed and analyzed using a SEM (Zeiss Sigma 500).

3. Experimental results and discussion

Fig. 2 presents the EBSD analysis results of the specimens with different treatments. Fig. 2(a–c) displays the orientation imaging microscopy (OIM) maps on selected regions, while red represents [001] orientation, green represents [101] orientation, and blue represents [111] orientation. It is clear that the initial microstructure shown in Fig. 2(a) was consisted of coarse and inhomogeneous equiaxed grains. Fortunately, many refined grains were obtained after LP, while the specimen processed by CLP exhibited the smallest-size grains. It can be concluded from Fig. 2(d–f) that 70.5% of the grains size exceeded 40 μm for the untreated specimen, while only 35.0% and 24.5% of the

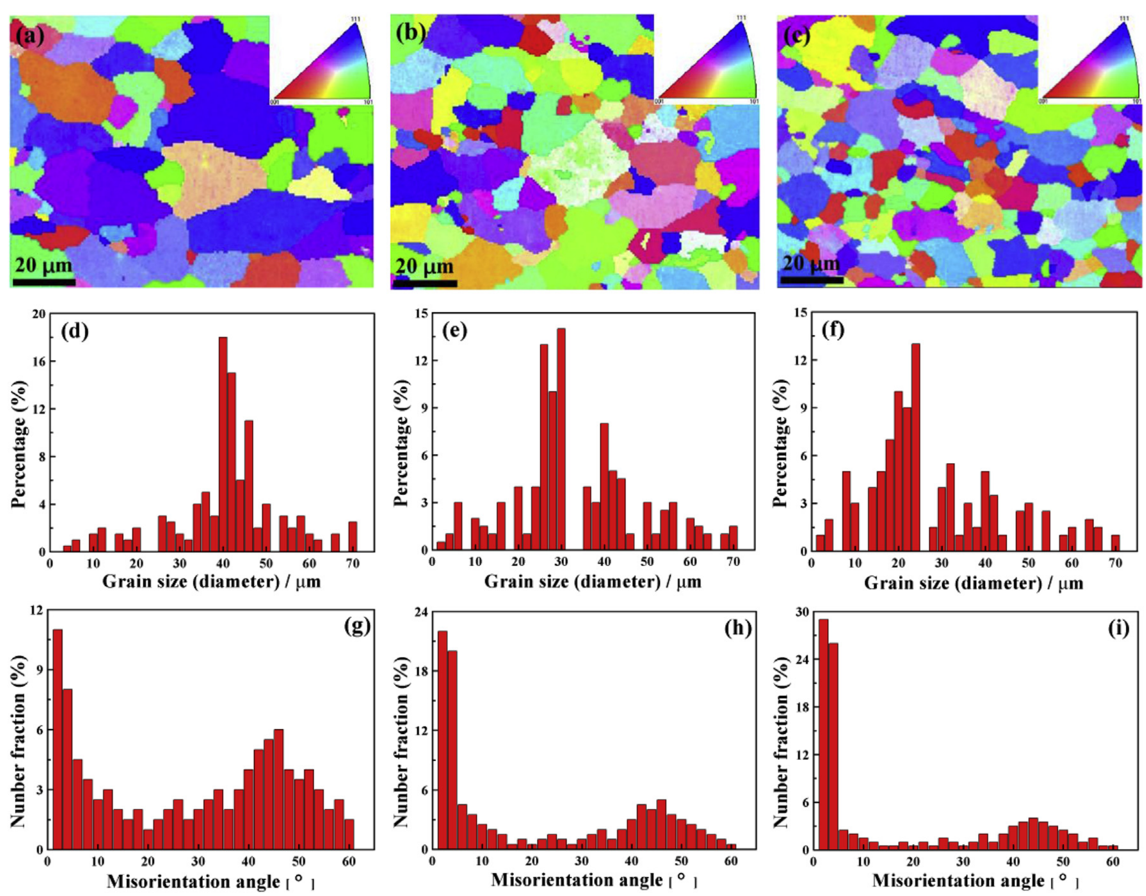

Fig. 2. OIM maps and the distribution of grain size as well as misorientation angles on the specimens treated by different treatments: (a, d and g) Untreated, (b, e and h) RT-LP and (c, f and i) CLP.