Materials Science and Engineering A 539 (2012) 360–368

Contents lists available at SciVerse ScienceDirect

Materials Science and Engineering A

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

Effect of repeated impacts on mechanical properties and fatigue fracture morphologies of 6061-T6 aluminum subject to laser peening

J.Z. Zhou[a], S. Huang[a,*], J. Sheng[a], J.Z. Lu[a], C.D. Wang[a], K.M. Chen[b], H.Y. Ruan[a], H.S. Chen[a]

[a] School of Mechanical Engineering, Jiangsu University, Zhenjiang 212013, PR China
[b] School of Material Science and Engineering, Jiangsu University, Zhenjiang 212013, PR China

ARTICLE INFO

Article history:
Received 9 September 2011
Received in revised form 26 January 2012
Accepted 28 January 2012
Available online 6 February 2012

Keywords:
Electron microscopy
Aluminium alloys
Thermomechanical processing
Fatigue
Fracture

ABSTRACT

The effect of repeated impacts on mechanical properties and fatigue fracture morphologies of 6061-T6 aluminum subject to laser peening (LP) were investigated. Compared with the untreated samples, nano-hardness and fatigue lives of the samples subjected to 1-3 LP impacts increased by 18.1–59.1% and 7.3–99.4%, respectively. Residual stress presented compressive state on the superficial layer of the samples after LP, and the value increased with the increase of the impact number. LP caused the location of fatigue crack initiation (FCI) transferring from the top surface to sub-surface, and the distance from FCI to the top surface increased with the increase of the impact number. Meanwhile, the fatigue striation spacing (FSS) on the fatigue crack growth (FCG) area decreased with the increase of the impact number. In addition, the enhancement mechanism of LP on the resistance of FCI and FCG were discussed.

1. Introduction

Surface modification technologies have been widely employed in industry to reduce costs and avoid the requirements for expensive materials [1,2]. Compared with the traditional process such as shot peening [3], deep rolling [4] and cold extrusion [5], laser peening (LP) is a more effective anti-fatigue technology for metallic materials, which generates high-pressure shock wave and then introduces compressive residual stress of several hundred MPa by exposing metallic samples to high power density (GW/cm^2), short pulse (ns level) laser beam [6–8], and the material properties such as fatigue strength, stress corrosion, wear performance and fretting property can be significantly improved [9–12]. Nowadays, many attentions have been paid to the effects of different processing parameters on the strengthening effect induced by two-sided LP [13–20].

C. Rubio-Gonzalez et al. have examined the effects of the pulse density on mechanical properties of 6061-T6 aluminum (Al) and 2205 duplex stainless steel induced by two-sided LP, and the results indicated that the fatigue crack growth (FCG) rate decreased and the fracture toughness increased with the increased pulse density [15,16]. L. Zhang et al. found that the fatigue crack initiation (FCI) and FCG of 7050-T7451 Al alloy treated by four paths can more effectively be restrained than two paths during two-sided LP [17]. The study of J.M. Yang et al. showed that LP can effectively improve the FCI life and the FCG rate of 2024-T3 Al alloy with various pre-existing notch configurations [18]. K. Ding et al. found that the compressive residual stress on the surface of Ti–6Al–4V alloy obviously increased by increasing the target thickness from 1 to 3 mm, but the affected depth of compressive stress was not significantly improved during two-sided LP [19].

Most of the above researches have been focusing on the effects of LP processing parameters such as the pulse density [14–16], peened path [17] as well as the geometry of sample [18,19], but few attentions have been paid to the effects of the impact number on mechanical properties of alloy subjected to LP. Actually, LP with different impact numbers is important and necessary for enhancing the mechanical properties of many key components in engineering applications. Meanwhile, more attentions have mainly been paid to the surface deformation [13], residual stress [13–16], fracture toughness [15,16] as well as fatigue life [15–20] of metallic materials, but the changes of the FCI location and the fatigue striation spacing (FSS) on fatigue fracture morphologies as functions of the LP impact number are still pending. In fact, the characteristic of fracture microstructure can reflect macroscopic and microscopic performance of metallic materials, so it is crucial to understand the FCI and FCG mechanism of LP based on the fracture morphologies with different impact numbers.

The object of this work is to examine the effect of repeated impacts on mechanical properties and fatigue fracture morphologies of 6061-T6 aluminum subject to LP. Nano-hardness, residual

---

* Corresponding author at: Xuefu Road 301, Jingkou District, Zhenjiang 212013, PR China. Tel.: +86 511 88786318; fax: +86 511 88780241.
E-mail address: huangshu11@sina.com (S. Huang).

0921-5093/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
doi:10.1016/j.msea.2012.01.125

Table 1
Chemical composition of 6061-T6 aluminum alloy.

Composition	Mg	Si	Fe	Cu	Cr	Mn	Ti	Zn	Al
Wt.%	0.90	0.62	0.33	0.28	0.17	0.06	0.02	0.02	Bal.

Table 2
Mechanical properties of 6061-T6 aluminum alloy.

Yield strength, $\sigma_{0.2}$ (MPa)	Tensile strength, σ_b (MPa)	Elongation δ%	Elastic modulus, E (GPa)	Specific gravity, ρ (kg/m^3)	Possion's cofficient, ν
289.9	328	13.5	69.8	2672	0.33

stress and fatigue life of samples subjected to 1-3 LP impacts are discussed, and special attentions are paid to the changes of the FCI location and the FSS on fatigue fracture morphologies. Furthermore, the enhancement mechanism of LP on the FCI and FCG resistance are also revealed.

2. Experimental procedures

2.1. Experimental material

6061-T6 Al alloy was selected in the present work, and the chemical composition and mechanical properties were shown in Tables 1 and 2, respectively. 6061-T6 Al alloy was cut to the notched sample with a central hole of ϕ2 mm, and the dimension of sample was shown in Fig. 1. The samples were polished with SiC paper with different grades of roughness (from 400 to 1200), followed by ethanol ultrasonic cleaning.

2.2. LP processing parameters

High energy shockwave was induced by a Q-switched Nd: YAG laser system in Laser Technology Institute at Jiangsu University, operating at 5 Hz repetition-rate with a wavelength of 1064 nm. The laser energy was 5 J, and the footprint of laser spot with a diameter of 3 mm was top-hat and FWHM of the pulses was 10 ns. The processing parameters used in two-sided LP were shown in Table 3 in detail, and the LP treatment region as well as swept direction of the fatigue sample was shown in Fig. 1. LP was performed from point B and then along the Y direction successively. During the LP process, repeated 1, 2 or 3 impacts were carried out on each spot, and then the laser moved to irradiate the next spot. The overlapping rates between the adjacent spots in both X and Y directions were 50%, and the total LP region of one side was 6 mm × 15 mm. After finishing the treatment of one side, the laser moved to irradiate the other side. A water curtain with a thickness of 1–2 mm was used as the transparent confining layer and a professional aluminum foil with a thickness of 100 μm was used as an absorbing layer to protect the sample surface from thermal effect. A typical photo of sample treated by LP was shown in Fig. 1.

Table 3
The processing parameters used in multiple LP impacts.

Parameters	Value
Beam divergence of output (mrad)	≤0.5
Spot diameter (mm)	3
Pulse energy (J)	5
Pulse width (ns)	10
Repetition-rate (Hz)	5
Laser wavelength (nm)	1064
Export stability	≤±5%
Polarization	Horizontal
Beam profile	Top hat

2.3. Measurements of nano-hardness and residual stress

The measurements of the nano-hardness were performed by nano-indentation technique on a *Triboindenter*, *Hystron Corporation (USA)*, by using a Berkovich diamond indenter. The residual stress was determined by the X-ray diffraction method. Prior to the measurement of residual stress along the depth direction, the electropolishing material removal method was used. The measurements of nano-hardness and residual stress were repeated five times for each condition, and an average value was taken to analyze.

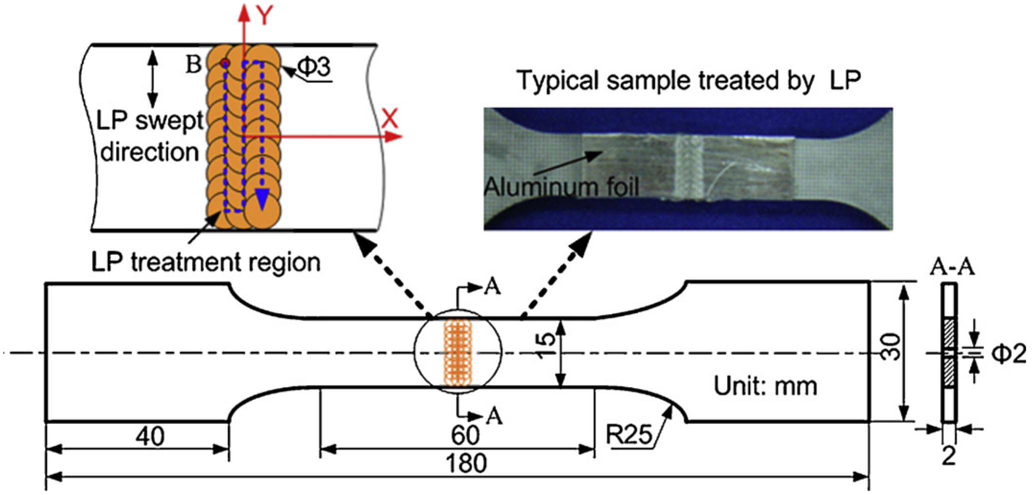

Fig. 1. The notched sample used in the fatigue test. (a) the LP treatment region and the LP swept direction, and (b) a typical photo of fatigue sample treated by LP.