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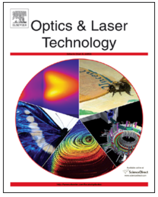

Pulsed Nd:YAG laser shock processing effects on mechanical properties of 6061-T6 alloy

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ABSTRACT

The aim of this paper is to investigate effects of single and double shot Nd:YAG laser shock processing (LSP) on residual stress, micro-hardness and tensile properties of 6061-T6 aluminum alloy. The X-ray diffraction technique was used to measure surface residual stress in LSP-treated 6061-T6 samples. The magnitude and directional dependence of the surface residual stress after single shot and double shot LSP were investigated with the $\sin^2\Psi$ method. The results show that laser shock processing can significantly increase surface compressive residual stress. In addition, micro-hardness of the LSP-treated sample was measured using a Vickers diamond indenter depending on the depth. The tensile tests of the single shot and double shot LSP-treated and untreated samples were carried out by the Schimadzu tensile testing machine having a video extensometer. Experimental results show that the values of micro-hardness, tensile strength and uniform elongation increase by LSP.

1. Introduction

Laser shock processing (LSP) is a recently developed and promising surface treatment technique and has been very effective in increasing strength of metals where the material is irradiated by short pulsed (typically 1–50 ns) and high intensity lasers (typically greater than 10^9 W/cm^2) [1–4]. Yilbas et al. [5] used high-power lasers to modify the material surfaces via LSP. According to recent published literature, the process has many industrial applications in aerospace and automotive industries [1–4]. Compressive residual stress is generated in depths in material greater than the conventional shot peening [6] as rapid expansion of plasma (partially ionized gas) is generated as a result of laser pulse–target material surface interaction. The target surface is coated with an opaque overlay like a black paint or metallic foil tape to increase the laser energy absorbance and avoid the thermal effect on the surface [7]. The target material is immersed in dielectric transparent confining medium (such as water, glass, etc.) which is called “confined ablation”. Based on this confined ablation mode, laser shock processing may be explained by a two-step process: (1) the rapid expansion of plasma generates compression on the treated area subjected to laser and so the surface layer broadens, then elastic and plastic deformation happens and (2) the surrounding material in which elastic deformation occurs reacts to deformed area, thus a compressive stress field is created on material surface. Fig. 1 shows that the LSP-treated area stretches during the interaction and the surrounding material reacts to deformed area after laser pulse is switched off [8]. The generated plasma pressure can be increased by a transparent confining medium. High pressure in the order of several GPas causes shock waves propagating in the target material and confining medium [9]. Plastic deformation occurs inside the material where peak pressure exceeds the Hugoniot elastic limit (equivalent to yield strength under shock conditions) of metal and residual stress takes place throughout the affected depth [10]. Compressive residual stresses therefore occur and develop at the surface [11]. Plastic strain decreases as the peak pressure of shock wave decreases. This will contribute to the improvement of strength and hardness of the laser shocked specimen [12].

LSP has clear advantages for components of complex geometry such as fastener holes in aircraft skins [8]. LSP is applied to many aerospace products, such as turbine blades and rotor components and, discs, gear shafts and bearing components [11]. It is asserted that the LSP-treated components can significantly enhance the resistance to fatigue, fretting and stress corrosion [13,14]. The process is similar to shot peening, but the shots are replaced by laser pulses and create residual compressive stresses deep into the surface of a part surface—typically five to 10 times deeper than conventional metal shot peening. Therefore it can be an alternative method for higher fatigue and mechanical properties [11,15]. Previously published experimental studies were focused mostly on the effect of fatigue properties of laser shock processed materials [1,2,8,11,16–20]. They found that laser shock processing can significantly improve the

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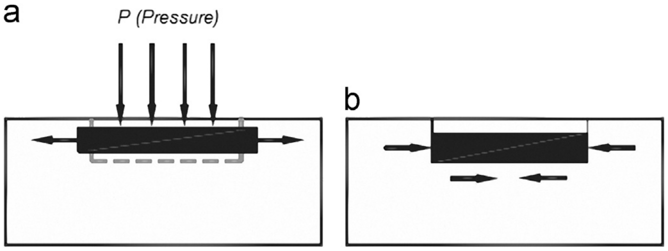

Fig. 1. The compressive residual stress formation during laser shock processing [8].

stability of the compressive residual stress in steel, aluminum and titanium alloys. There are a few papers [21,22] which investigated the tensile properties of laser shocked materials. For example, Lu et al. [21] improved the ultimate tensile strength and elongation of LY2 aluminum alloy by laser shock processing where shockwaves were induced by a pulse energy of around 3 J. Ren et al. [22] showed that laser shock processing which was performed by high power Nd: Glass laser enhances the yield strength and tensile strength of the 00Cr12 alloy.

Al 6061 is an Al–Mg–Si–Cu alloy used in automotive and aerospace applications both in the T4 (solution treated and naturally aged) and the T6 (peak aged) [23–25]. The present study reports the results of nanosecond LSP-treated 6061-T6 aluminum surface in underwater laser irradiation at 750 mJ laser pulse energy. The aim was to study tensile properties of 6061-T6 alloy in light of residual stresses which take place at material surface after LSP. It is of interest to investigate the effect of laser shots on the mechanical properties by LSP.

2. Experimental procedures

2.1. Experimental material

The chemical composition of 6061-T6 alloy used in this work is given in Table 1. The thickness of target material is 2 mm. The materials were cut by using a punch, successively cleaned in ethanol using an ultrasonic cleaner ready for the LSP process. Two different shape materials have been prepared for experiments. The first sample is of rectangular shape with dimensions of 20×20 mm^2 for hardness measurements and XRD analysis and the second one is a tensile specimen in accordance with ASTM E 8M-04 standard for tensile property, whose dimension is shown in Fig. 2.

2.2. Experimental procedure of LSP

Q-switched Neodymium-doped:Yttrium Aluminum Garnet (Nd:YAG) laser with a wavelength of 1064 nm was used. The LSP experiments were performed using a laser operating at 10 Hz repetition rate and with a pulse duration of 6 ns. Pulse energy of the laser system was 750 mJ and focal length of the lens was 150 mm. Laser beam spot size on the target was set to 1.5 mm with an overlap rate of 50% during LSP. The LSP procedure was carried out in two regimes: single shot and double shot on the target material surface. The opaque overlay which absorbs the laser energy and forms the plasma that maintains absorbance of laser energy until the end was an electrical black tape with a thickness of 130 μm. It also protects the sample surface from the thermal effect. Specimens were submerged into water which is the confining medium (Fig. 3). The thickness of the confining medium on target surface was about 2 mm. The processing parameters used in LSP are shown in Table 2.

Table 1
Composition of 6061-T6 alloy.

Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti
0.62	0.46	0.29	0.09	0.88	0.17	0.01	0.04	0.05

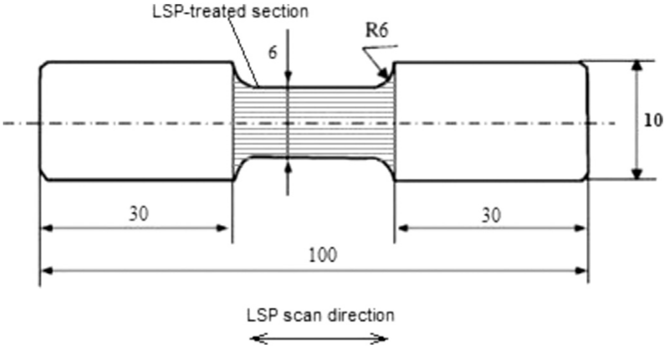

Fig. 2. The dimensions of the tensile specimen (unit: mm).

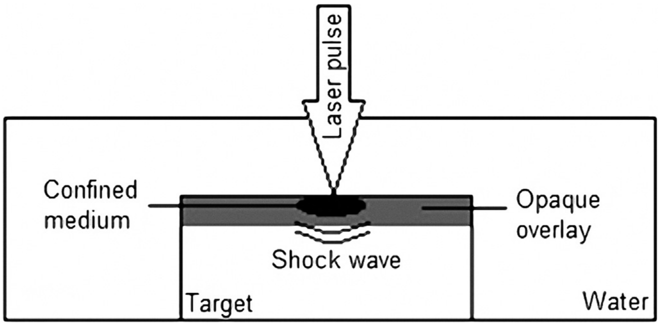

Fig. 3. Schematical view of principle of laser shock processing.

Table 2
Process parameters used in LSP.

Type	Value
Pulse energy (mJ)	750
Spot size (mm)	1.5
Repetition rate (Hz)	10
Pulse duration (ns)	6
Laser wavelength (nm)	1064

2.3. Measurement of hardness

The hardening effect of LSP was evaluated through micro-hardness analysis. The micro-hardness distribution of treated specimen was measured by using a Vickers FUTURE-TECH micro-hardness tester. A cross-section of the specimen was prepared for hardness testing and the hardness distribution was acquired under 50 g load and 10 s of hold time. The measurements were executed with a range of 50 μm and were repeated three times for each condition from which an average value was determined.

2.4. Measurement of residual stress

The residual stresses at the surface after LSP were measured using an X-ray diffractometer with $\sin^2 \Psi$. The X-ray source was Cr Kα ray and the experiments were carried out on (311) diffraction