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Investigation on effect of laser shock processing on fatigue crack initiation and its growth in aluminum alloy plate

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ABSTRACT

A series of contrasting experiments were carried out to examine the effects of laser shock processing (LSP) on fatigue properties of slot in 7075-T6 aluminum alloy plate. Both side surfaces of slot were subjected to LSP. The surface topographies were observed and the residual stresses were tested. The treated and the un-treated specimens were pulled by the fatigue cyclic loading respectively. The fatigue crack propagating processes were recorded, and the fatigue fracture microscopic morphologies were analyzed by scanning electron microscope (SEM). Experimental results and analyses show that LSP induces micro-dent on surface and squeezes the compressive residual stresses into surface layer of specimen. It can remarkably delay the micro-crack formation, and transfer the location of fatigue crack initiation from top surface to sub-surface. The spacing of fatigue striations on the treated specimen fatigue fracture obviously decreases. Therefore, the fatigue life of specimen after LSP treatment significantly increases.

1. Introduction

Laser shock processing (LSP) is a novel surface modification technology. It employs high-power laser to impose strong shock wave on material surface to refine material structure and induce beneficial compressive residual stress into surface layer [1–3], so it can improve metal material mechanical strength, fatigue property and corrosion resistance [4–7]. Comparing with the traditional processing techniques such as shot peening, deep rolling, it can be controlled precisely for treatment location, and it can induce far deeper depth of compressive residual stress [8], so it seems to be a competitive technique to provide a more robust fatigue enhancement [9–11].

Recently, a series of significant experimental work has been conducted to assess effect of LSP on fatigue crack growth rate and fatigue life [12–17]. Rubio-González et al. devoted to effects of different laser pulse densities on the fatigue properties of 6061Al and 2205 duplex stainless steel [14,15]. Chahardehi et al. concentrated on the influence of residual stress induced by LSP to fatigue crack growth rate of steel plate [16]. Huang et al. found out that coverage area of LSP had great influence on modified fatigue properties of 6061-T6 aluminum alloy by LSP [17]. These investigations have verified that LSP can arrest fatigue crack propagation (FCP). However, these researches focused on compact tension specimens (CTS). In order to satisfy the CTS requirements, a small pre-crack was made in specimen before fatigue testing, which resulted in difficulty in observing the effect of LSP on delay crack formation and transformation of the fatigue crack initiation (FCI) location during the testing. Up to now, few references disclose what percentage of delay time to forming micro crack accounts for the whole prolonging fatigue life contributed by LSP. So the enhancement mechanism of fatigue property by LSP is worth investigation.

The aim of present work is to evaluate comprehensively the effects of LSP on crack forming and its propagation behaviors of slot in 7075-T6 Al alloy plate. The surface micro-topographies and residual stresses were investigated. The crack growth lengths were recorded, and fracture surfaces were studied to demonstrate the fatigue crack initiation sites and fatigue crack spacing. The fatigue benefits offered by LSP have been revealed in aluminum alloy.

2. Experiments

2.1. The preparation of specimens

The tested material was 7075-T6 aluminum alloy, which has advantages of super-high strength, excellent hot workability, eminent corrosion resistance, etc [18]. Its chemical composition (wt%) is: 0.40 Si, 0.50 Fe, 2.0 Cu, 0.30 Mn, 2.9 Mg, 0.28 Cr, 6.1 Zn, 0.2 Ti. Its ultimate tensile strength is 572 MPa, tensile yield strength is 503 MPa, elongation is 11% and elastic modulus is 70 GPa.

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The tested specimens were tailored from 7075-T6 aluminum alloy plate with 4 mm thickness by a wire electrical discharge machine (EDM). Its outer size was 62.5 mm × 60 mm × 4 mm. A narrow slot with 3 mm width was distributed symmetrically along the axis of specimen, and its tip was a semicircle hole with a diameter of 3 mm, as shown in Fig. 1. In order to eliminate the effect of electrical discharge processing, the polished sand papers were used to remove burrs from edges and reduce cutting bump mapping.

2.2. LSP experiments

LSP experiments were performed on a Q switched Nd: YAG laser operating at 10 Hz with a wave length of 1064 nm, laser local diameter of 3 mm, laser energy 3 J per pulse and the Full Wave at Half Maximum (FWHM) of the pulse of 8 ns. Experimental set-up of LSP was shown as in Fig. 2. Before laser irradiation, the local surface to be peened was coated with a special black adhesive tape and a flowing water curtain in sequence. The black tape was served as a sacrificial ablative layer, and the flowing water was used as a confining layer. The specimen was fixed on a manipulator to implement movement along the *x*-, *y*- and *z*-directions during successive laser irradiations. Then, a single laser pulse was emitted from the laser, and subsequently divided into the same two pulses by a beam splitter. The laser beam was focused to a desired diameter using a focal length lens. Each laser pulse passed respectively through the confining layer and irradiated on the ablative layer, and induced high temperature and high pressure plasma in an ultra-short time. The high pressure caused stress wave propagating into the material. During laser irradiation, the black tape, instead of metal material, was ablated and kept the heat damage from the metal, so LSP was a cold process with mechanical, not a thermal process [8].

During LSP experiment, both side surfaces of slot were shocked simultaneously by two laser pulses with the same parameters. In order to obtain a desired treatment area with 9 mm × 9 mm on each surface and achieve homogeneous surface residual stress in this region, LSP was applied spot by spot [14,16,17]. The swept direction of laser was also shown in Fig. 2, and the overlapping rate between the adjacent spots in horizontal and perpendicular directions was 52%.

2.3. Surface morphology and residual stress measurement

The surface micro-morphologies at the untreated region and the treated region were measured with an optical profilometer WYKO NT110. The residual stresses of the specimens were measured by the $\sin^2\psi$ method with X-ray diffraction (XRD) meter. The X-ray source was from Cr Ka radiation operated at a voltage of 20 kV and current of 8 mA. The fracture surface morphologies of specimens after fatigue tests were analyzed by JSM-6700F field emission scanning electron microscopy (SEM), which was used at voltage of 15 kV.

2.4. Fatigue testing

A series of the replicate fatigue tests were performed on a PLN-100 fatigue tester at the room temperature (18 °C) in the air. The parameters in each case were controlled by computer to

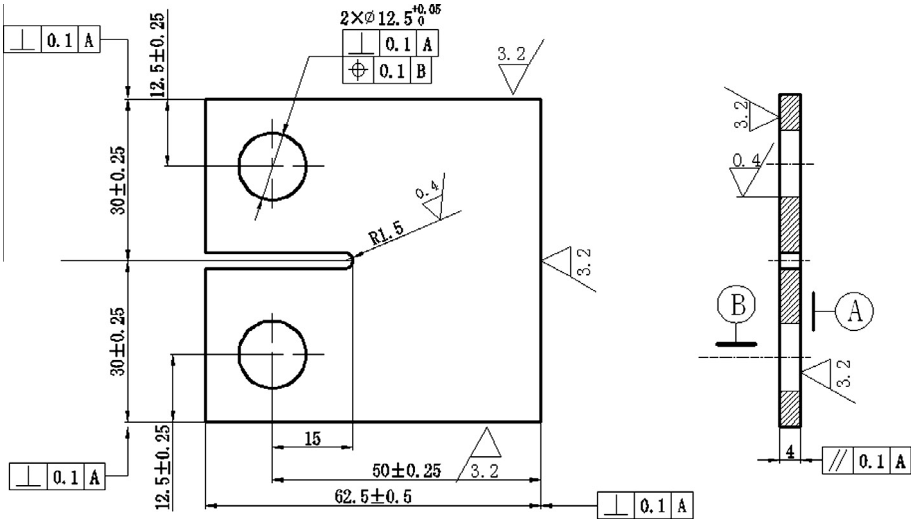

Fig. 1. The size of specimen.

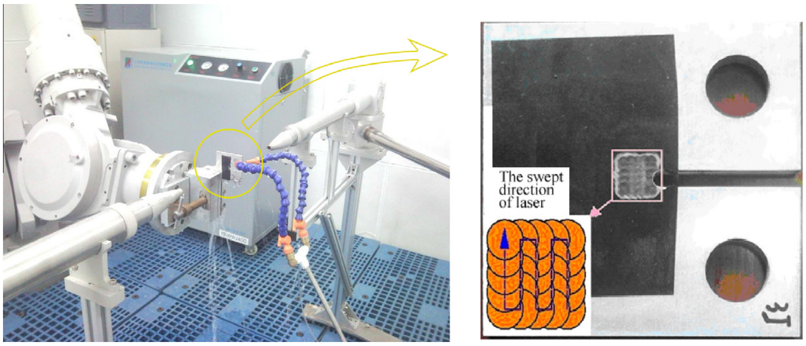

Fig. 2. Experimental set-up of LSP.