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Improving creep properties of 7075 aluminum alloy by laser shock peening

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ABSTRACT

Effects of laser shock peening (LSP) treatment on the creep properties and microstructural evolution of the surface of 7075 aluminum alloy were investigated in this work. The microstructures of the LSP-treated and untreated specimens before creep were characterized by transmission electron microscopy (TEM) and scanning electron microscope (SEM). Creep rupture was then investigated. After creep, electron backscatter diffraction (EBSD) was conducted to analyze the peaks of the misorientation angle for the as-machined and LSP-treated samples. SEM was performed to observe the fracture surface. Above results proved that LSP could enhance the steady-stage creep life by 97% at 350 MPa/200 °C, 307% at 350 MPa/200 °C, and 120% at 300 MPa/200 °C. The mechanism for the improved creep properties of 7075 aluminum alloy by LSP was analyzed by TEM observation. Moreover, the creep process and mechanism of the variation of their microstructures were discussed. LSP had a beneficial effect on the improvement of surface microstructure comprised of the increase of dislocation density and the refinement of dispersoids, which would hinder the dislocation movement, decrease the growth of tensile texture and cracks and lower the creep rate. So LSP can effectively enhance the creep resistance of 7075 aluminum at the elevated temperature and working stress.

1. Introduction

With the emergence of the energy and resource crisis, lightweight has become a core problem for the development of transportation such as automobile, high speed train, etc., so more and more aluminum alloy have been widely applied as structures parts. Most of the damages originate from the surface of the work-pieces. Surface integrity has a significant impact on the performance of products [1, 2] and much research has been devoted to the related studies, such as shot peening [3–5], cold rolling [6, 7], oil jet peened [8] and laser shock peening [9–13]. The effect of shot peening (SP) on high cycle fatigue [3] and fretting fatigue [5] of 7xxx Al alloy were investigated. Microstructure and texture of Al alloy during cold rolling were also exhibited [7].The relationship between microstructure and mechanical properties of oil jet peened aluminum alloy AA6063-T6 was studied [8]. Laser shock peening (LSP), as a method for grain refinement, can effectively improve the surface quality [9], increase the corrosion resistance [10] and enhance the fatigue performance [11]. For example, Trdan et al. [12] reported that a more stable passive/oxide film, which could reduce both crystallographic and surface-hemispherical pitting, was triggered easily on the treated surface by LSP. In another study, Bergant et al. [13] also investigated the influence of LSP on the fatigue performance and they found the crack growth threshold of aluminum alloy 6082-T651 decreased by 60% after LSP treatment. Zhang et al. [14] selected LY2 aluminum alloy treated by LSP for the turbojet engine blade. Their results showed that LSP enhanced the fatigue life of LY2 alloy by inducing the high compressive residual stresses and micro-hardness on the treated surface. Zhou et al. [15] found that multiple LSP impacts could effectively prevent the growth of fatigue crack, and the fatigue resistance and fatigue life increase with the increase of the impact number. The above studies contributed greatly to the safe use of Al alloy, however, most of the researches have focused on the damage and fracture property of Al alloys at room temperature.

Among of Al alloys, 7075 aluminum alloy are widely used in the aerospace industry, construction machinery and automobiles owing to their good corrosion consistency and high mechanical properties. In the aforementioned conditions, temperature is a crucial factor. When the temperature is above 100 °C, the tensile strength of 7075 aluminum alloy drops sharply [16]. Under long periods of constant temperature and force, plastic deformation will slowly occur even if the stress is less than its yield strength. The behavior of plastic deformation is generally called creep. Moreover, creep is one of the most common forms of damage at high temperature. Many researchers have aimed to improve the creep properties of 7075 aluminum alloy. Jahromi et al. [17] found

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that homogeneous precipitation can improve the creep resistance of 7075 aluminum alloy; the same is especially true by adding Zr elements, which make the precipitated phases fine and uniform and thus improved creep fracture resistance. Heat treatments can also improve the creep resistance of 7075 aluminum alloys [18–20]. Srivastava et al. found that a reasonable aging treatment could improve the creep resistance of 7075 aluminum alloy at low stress levels. LSP can effectively improve the mechanical properties of 6061-T651 alloy at elevated temperatures [21]. Orozco-Caballero et al. [22] reported that equal channel angular pressing (ECAP) improved the creep resistance of Al–7 wt% Si alloy by changing the dislocations, low angle boundaries and grains sizes. As mentioned above, LSP can also refine the grains and induce high density of dislocations [23]. However, few reports have explored the effects of laser shock on improving the creep resistance of 7075 aluminum alloy. In the current work, tensile creep tests on 7075 aluminum alloy before and after laser shock peening (LSP) were carried out. Creep properties and the microscopic mechanism of the alloys from 150 °C to 250 °C were investigated to provide a basis for the application of these alloys.

2. Experimental details

2.1. Materials

7075 aluminum alloy used in this study was a commercially available plate with a thickness of 2 mm. The actual composition of the specimen was measured by inductively coupled plasma–atomic emission spectrometry (OPTIMA 8000DV). The measured results in wt% were Al bal., Fe 0.5, Cu 2.0, Mg 2.1, Mn 0.3, Zn 5.5, Si 0.4, Ti 0.2, Co 0.03, Ni 0.023, and Cr 0.19. The metal used in this study was not subjected to any heat treatment. The original microstructure of as-received 7075 aluminum alloy material observed by optical microscope is shown in Fig. 1. Moreover, its mechanical properties are listed in Table 1 and the dimensions of the tensile creep specimens are shown in Fig. 2. All specimens were machined according to ASTME139-2006 and along the longitudinal (L) and long -transverse (LT) rolling direction [24].

2.2. LSP

In the Laser Technology Institute of Jiangsu University, LSP experiments were accomplished using a nanosecond Q-switched Nd:YAG (GAIA-R, France Thales Co., Ltd.) laser system. The main process parameters were as follows: (1) a wavelength of 1064 nm with a pulse width of 10 ns, (2) a repetition rate of 5 Hz, (3) a laser pulse energy of 10 J, (4) a laser spot with a diameter of 2 mm, and (5) an overlap rate of 50%. Prior to LSP, a protective coating of aluminum tape with a thickness of 0.1 mm was used on the specimens to protect the LSP-treated surface from laser thermal injury. During the LSP treatment, flowing water with a thickness of ~1 mm served as a confining layer that covered the treated surface to improve the absorption of laser energy. Fig. 3 shows the treated path of the specimens.

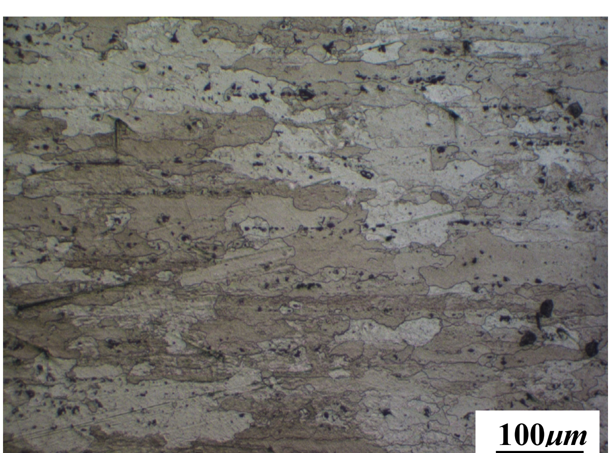

Fig. 1. The cross-sectional microstructure of as-received 7075 aluminum alloy.

Table 1
Mechanical properties of 7075 alloy.

Mechanical properties	Tensile strength (MPa)	Yield strength (MPa)	Elongation (%)
Value	541	476	8

2.3. Creep tests

All creep experiments were performed with a high-temperature tensile creep endurance test device (UHRD504-B1, made in China), as shown in Fig. 4(a). Treated and untreated specimens were aligned at the middle of the furnace, as shown in Fig. 4(b). Maximum force of this experimental equipment was 50 kN. The system featured a measurement scale of 0.2–50 kN, with an error < 0.5%, and a resolution of 1/200000 that was maintained throughout the process. The highest temperature of the machine used on the tensile plate can reach 1000 °C. The deformation measurement range was 0–10 mm, the deformation indication error was < 0.001 mm, and deformation resolution was 0.001 mm. The laboratory used remote communication in a control room.

The process and technology of the creep tests were in accordance with the standards of metal tensile creep and endurance test method (ASTME139-2006). According to Ref. [25], the creep temperature of aluminum alloy was determined to be 150 °C, 180 °C, 200 °C, 220 °C, and 250 °C. As shown in Table 1, the yield strength of aluminum alloy was 476 MPa. To ensure effective and normal creep tests, we selected 150, 250, and 300 MPa as the experimental forces.

2.4. Characterization techniques

To obtain and compare the typical microstructures of the LSP-treated and untreated samples, we cut the TEM foil from the surface, subjected it two-jet electro-polishing and ion milling (as shown in Fig. 5(b)), and examined it via transmission electron microscopy (TEM, JEM-2100). After creep fracture occurred, the fracture surfaces of the creep specimens were also observed by scanning electron microscopy (SEM, Zess Sigma 500). To further explore the mechanism of LSP on creep, we cut the special test samples from the creep failure parts, as shown in Fig. 5(a). The testing surfaces were ground using polishing paper with grades ranging from #1500 to #2000. Afterward, they were electrochemically polished in an acid solution ($HClO_4$:C_2H_5OH = 1:9) at the voltage of 20–30 V for 40–60 s. Their micro-textures were then investigated using SEM equipped with an electron backscatter diffraction (EBSD) detector. Scanning was performed with a step size of 0.5 μm and tilting angle of 75°. Measurement results were analyzed with HKL Channel 5.

3. Results and discussions

3.1. TEM and SEM observations

Fig. 6 shows the TEM images of the LSP-treated and untreated 7075 aluminum alloy. Fig. 6(a) exhibits a typical bright-field image of 7075 A1 without LSP and Fig. 6(b)–(d) illustrate the images of 7075 A1 alloy with LSP. Fig. 6(e) is the energy dispersive spectrometer (EDS) analysis of Point E in Fig. 6(a).

Fig. 6(a) presents coarse grains, including the presence of α-Al