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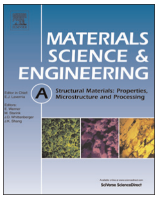

Effects of laser shock peening on stress corrosion behavior of 7075 aluminum alloy laser welded joints

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ABSTRACT

7075 aluminum alloy weldments were processed by an intensive process known as laser shock peening (LSP), meanwhile its stress corrosion behaviors were observed by scanning electron microscopy (SEM) and slow strain rate tensile (SSRT) tests. Results showed that the effect of LSP on corrosion behavior of the joint was fairly useful and obvious. With LSP, the elongation, time of fracture and static toughness after the SSRT test were improved by 11.13%, 20% and 100%, respectively. At the same time, the location of the fracture also changed. LSP led to a transition of the fracture type from transgranular to intergranular The reasons for these enhancements of the joint on corrosion behavior were caused by microstructure, residual stress, micro-hardness, and fracture appearance.

1. Introduction

High strength aluminum alloys like 7075 are commonly used in the aerospace industry due to their light weight and high strength [1]. Although 7075 aluminum alloys exhibit an even higher specific strength, they are not widespreadly used in many other fields. The key obstacles leading to this disregard are weldability problems such as hot cracking and porosity in the weld. Therefore, taking into account these considerations, laser welding technology is an adequate option to join these alloys, as it allows a higher localization and smaller melting pool, considerably reducing the energy required than with other welding technologies [2]. Laser welding, in fact, can provide many advantages over traditional welding. First of all, laser devices can save time in commercial laboratories because the welding is entirely carried out directly on the master cast. This means that assembly inaccuracies caused by transfers from the master cast and further investments are reduced [3]. Secondly, the heat source is a concentrated and high powered light beam which is able to minimize distortion problems on prosthetic pieces [4–5]. Lastly, high powered diode lasers, CO_2 lasers, Nd:YAG lasers, and fiber lasers are all suitable for welding thin plates, which makes the welding processing more steady and the surface of the welding seam smoother.

Laser shock processing (LSP) is one of the most important and innovative surface modification technologies currently available and is commonly perceived as a competitive alternative [6,7]. LSP process utilizes high energy laser pulses that are fired at the surface of a metallic part. The high strength impact waves generated from the laser beams (high power density: GW/cm^2, short pulse: ns) then interact with the surface of metallic materials [8] and introduce compressive residual stress to a depth of a few millimeters under the surface [9]. Mechanical properties of metallic materials such as fatigue [10–15], corrosion resistance [9,16–17], and wear [18] are also improved by such LSP impacts.

The main purpose of this work is to discuss the effects of LSP technology on the stress corrosion resistance of 7075 aluminum alloys weldments. Through a series of tests, 7075 aluminum alloys weldments both with and without LSP impacts are studied, and the results are explained by the analysis of mechanical properties and microstructures.

2. Experimental procedures

2.1. Laser welding

The samples used in the present study were 7075 aluminum alloy plates with a thickness of 4 mm and the chemical composition of which is shown in Table 1. The alloy sheet was cut using a liner cutting machine according to the specific size of $250(w) \times 150(l) \times 4(h)$ mm^3. The workpiece surfaces were then cleaned and

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Table 1
The chemical composition of 7075 Aluminum alloy (wt%).

Composition	Zn	Cu	Si	Mn	Fe	Mg	Cr	Ti	Al
Percent (wt%)	5.5	2.0	0.4	0.3	0.5	2.1	0.19	0.2	Other

Table 2
Optimized process parameters for laser welding.

Parameter	Laser power	Welding speed	Shielding gas	Flow rate of shielding gas	Focal position
Unit	kW	m/s	–	l/min	mm
Value	5.5	0.015	Argon and He	20	0

degreased ultrasonically in pure ethanol prior to laser welding.

The aluminum alloy weldments were created using a YLS-4000 fiber laser (IPG, USA). The properties of the welded samples were initially evaluated before the procedure and the optimized welding parameters which resulted from the parameter variation are given in Table 2 below.

2.2. Laser shock peening

The weldments were machined in a direction perpendicular to the weld line by a wire cutting machine in order to prepare samples with a regular shape and a thickness of 4 mm. All of these samples were polished with SiC paper with different grades of roughness, and then cleaned in deionized water. Subsequently the samples were degreased in ethanol by ultrasonication. Since aluminum alloys have a high reflectivity, prior to LSP procedure the samples were covered by an ablative layer of aluminum tape with a thickness of 0.1 mm and a tamping layer of flowing water with a thickness of about 2 mm. This step was taken in order to improve absorption from the laser energy. The laser that was used has an irradiance of 5 GW/cm^2 and a pulse duration of 15 ns. The chosen LSP parameters are shown in Table 3 below.

2.3. Test of residual stress

Residual stress can significantly affect the engineering properties of materials and its structural components, notably fatigue life, distortion, dimensional stability, corrosion resistance, and brittle fracture. Residual stress measurements were performed using a commercial X-350A X-ray diffractometer (XRD), equipped with a pole figure goniometer, operating at 22 kV and 6 mA, and employing Ni filtered Co K_α radiation. The measurements were taken using 2θ scans from 68.5° and 72° with 0.01° per step and 1 s per step, measuring (3 1 1) peak positions at 10 different tilt angles [19]. The allowable measurement deviation of X-350A X-ray diffractometer is 20 MPa, the value and the deviation of residual stress was printed automatically. This test was repeated when the deviation exceeded 20 MPa. In this study, residual stress of the crown profile was tested, the measurement was repeated three times for each conditions, and the average values were obtained.

Table 3
LSP process parameters.

Wavelength (nm)	Pulse duration (ns)	Pulse energy (J)	Diameter of laser spot (mm)	Overlapping rate (%)
1064	15	8	2	60

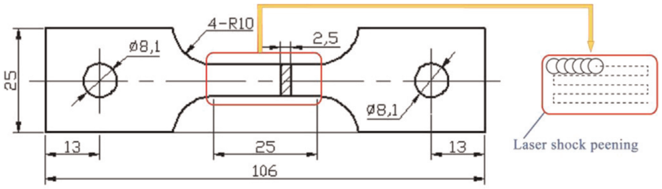

Fig. 1. Dimensions of the specimen used in the SSRT test (unit: mm).

2.4. Stress corrosion testing

Flat samples with the dimensions shown in Fig. 1 below were machined using a liner cutting machine, polished to 1200 grit, degreased with acetone, dried and then put in desiccators for 1 h before straining. Samples with and without LSP were strained at the rates of 1 × 10^{-6}/s [20]. Then the specimens were immersed in a 3.5 wt% NaCl solution.

2.5. Morphology observation

In this study, morphology observations were divided into two groups, which included the surface morphology observation before corrosion and the fractograph morphology observation after stress corrosion.

3. Results and discussion

3.1. Microstructure and microhardness

The specimens were polished and then the welded zone (WZ) of the cross sections with and without LSP was observed, as shown in Fig. 2. Many defects such as stomata, slag and coarse columnar crystals existed in the WZ of the 7075 aluminum alloy laser welded joint, as shown in Fig. 2(a), while finer and more homogeneous microstructures were obtained after LSP treatment, as shown in Fig. 2(b). In this study, we found that LSP could diminish the number of columnar crystals and accelerate the formation of equiax crystals in the WZ. The same result had been reported by Lu et al. in Ref. [21]. Lu and his colleagues also observed grain refinement and residual stresses after LSP treatment. The aforementioned changes in the microstructure of the specimens after LSP are significant, which is beneficial for enhancing the mechanical properties of such weldments, especially for the improvement of their impact toughness [22,23].

In order to explore the microstructure evolution, transmission electron microscopy images of the weld zone near the surface are presented in Fig. 3. In the WZ of the specimens without LSP, the TEM micrographs reveal a coarser grains boundary in length about 2 μm (Fig. 3(a)),but it is revealed that a remarkably fine distribution of nano-grains ranging from approx. 100 nm to 500 nm in length (Fig. 3(b)). That was caused by the high power density (5 GW/cm^2). Only a little dislocation and dispersoid appear in the specimens without LSP, as shown in Fig. 3(c). In comparison with the peened specimen (Fig. 3(d)), the dislocation density is evidently higher, with various dislocation structures as an effect of severe plastic deformation induced by laser shock waves during LSP treatment. Fig. 3(d) depicts a large amount of dislocation lines and dislocation tangles in the specimens. Liu et al. have reported that various dislocation structures with the formation of SF and smaller grains were near the twin boundary, they also proposed that these smaller grains were the dislocation source to facilitate plastic deformation, as well as barriers to block further dislocation movements, therefore, increasing both strength and ductility [24].

A schematic presentation for the grain refinement mechanism