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ARTICLE

Fatigue Lifetime of Laser-MIG Hybrid Welded Joint of 7075-T6 Aluminum Alloy by *in-situ* Observation

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Abstract: The fatigue lifetime of the laser-MIG hybrid welded joint of 7075-T6 aluminum alloy was studied by in-situ observation. The results show that there exists a strong relationship between the fatigue crack initiation lifetime and fatigue failure lifetime. For the base metal specimens the ratio of fatigue crack initiation lifetime and fatigue failure lifetime is about 64.5%, while for the welded joint specimens it is about 20.2%. The observation of fatigue fracture surface indicates that there are a large number of dimples in the base metal specimens, while lots of gas porosities appear in the welded joint specimens instead. These gas porosities are regarded to be the reason of lower fatigue crack initiation lifetime.

Key words: aluminum alloy; welded joint; *in-situ* observation; fatigue lifetime

7075-T6 aluminum alloy is a heat-treatable aluminum alloy with low density, moderately high strength, excellent corrosion resistance and good processing performances. It has been widely used in the transport industry, and is one of the most important structural materials in the aerospace industry[1-5]. Elimination of fasteners in these components by welding would provide considerable mass savings and a reduction in manufacture cost. In aluminum alloy welding, traditional methods are to join the components through arc welding or laser welding. However, arc welding cannot meet the needs of modern welding industries due to the wider heat-affected zone and the greater thermal stress after welding[6-8]. While for laser welding, the low melting-point elements in aluminum alloy are easily vaporized and lost from the weld region, leading to the formation of gas porosity, cracking susceptibility, changes of composition and mechanical properties, and other defects[9-12].

Laser-metal inert gas (MIG) hybrid welding is a combination of laser welding and arc welding, and has many advantages over laser welding or arc welding, such as elimination of undercut, prevention of porosity formation and modification of weld compositions[13-15]. S. C. Wu et al.[16] studied the laser-MIG hybrid welded joint of 7075-T6 aluminum alloy by means of high-resolution synchrotron radiation X-rays. They found that the strength loss of welded joint was due to the excessive evaporation of elemental Zn and the significant inverse segregation of elemental Cu in central fusion welds, whereas the gas porosity has little influence on the static strength of hybrid welds. Yan Jun et al.[17] studied the effect of welding wires on microstructure and mechanical properties of an aluminum alloy in CO_2 laser-MIG hybrid welding, and found that the tensile strength and elongation of welds decreased due to the formation of eutectic phases in fusion zone. Yan Shaohua et al.[18,19] investigated the microstructures, mechanical properties and fatigue strengths of laser-MIG hybrid welded joint of aluminum alloy. They found that the fatigue strength of the laser-MIG hybrid welded joint was better than that of the MIG welded joint, and by the fatigue fracture surfaces analysis, it was found that gas porosity was the main reason for the decrease of the fatigue strength of the hybrid welded joint. It is noteworthy that there are few reports on the fatigue crack initiation and propagation behavior of laser-MIG hybrid welded joint of 7075-T6 aluminum alloy, especially the

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real-time observation of fatigue crack initiation and propagation behavior. In this research, fatigue crack initiation lifetimes and fatigue failure lifetimes of base metal and welded joint of 7075-T6 aluminum alloy were studied by an *in-situ* fatigue method, and based on the experimental results, a new method was used to evaluate the fatigue lifetime of base metal specimens and welded joint specimens. In addition, the microstructure and fractography of base metal and welded joint were also studied. Some interesting results have been obtained.

1 Experiment

The laser-MIG hybrid welded joint of 7075-T6 aluminum alloy was used in this study. The 7075-T6 aluminum alloy plates with a thickness of 2 mm were cut into sheets of 240 mm × 60 mm. The filler wire was ER5356 (Φ1.2 mm). The chemical composition of 7075-T6 aluminum alloy and filler wire are given in Table 1. Before welding, the joint surfaces were abraded with sandpaper in order to remove any dirt or grease adhering to the surface. The direction of welding was parallel to the rolling direction. Laser-MIG hybrid welding was performed by incorporating a fiber laser (YLR-4000) with a gas metal arc welding (GMAW, Fronius TPS4000) power source. The 99.999% pure argon gas with a flow rate of 45 $\mathrm{L\cdot min^{-1}}$ was selected as the shielding gas. To avoid reflection, the laser was inclined by approximately 10 degree, and the arc torch was inclined by 70 degree with the sample plane. Detailed parameters are listed in Table 2.

Fatigue specimens of welded joint were cut from the welded plate. The cutting position and dimensions are shown in Fig.1. The fusion zone of welded joint was adjusted to be at the middle of the gauge section during cutting. The fatigue specimens of base metal were cut from the primary plate with the same dimension of welded joint specimens. All the specimens were mechanically polished for the *in-situ* fatigue observation. The microstructures of both welded joint and base metal were examined by optical microscopy. The optical microscopy specimens were prepared with a standard metallographic technique and were etched with Keller's reagent (2 mL HF, 3 mL HCl, 5 mL HNO_3, and 190 mL H_2O).

The *in-situ* fatigue tests were carried out in the vacuum chamber of SHIMADZU SS-550 with a specially designed servo-hydraulic fatigue machine for fatigue loading. The stress-controlled tension–tension fatigue tests with a sinusoidal waveform signal (stress ratio $R = 0.1$, frequency=10 Hz) were conducted in vacuum (10^{-4} MPa) at room temperature. The loading frequency can be changed from 10 Hz to 0.10 Hz when recording. The fatigue crack initiation lifetimes and fatigue failure lifetimes of the specimens under the peak stress were recorded. Fatigue fractured morphology of various specimens was examined by a scanning electron microscope (SEM).

2 Results and Discussion

2.1 Microstructures

Fig.2 shows optical micrographs of laser-MIG hybrid welded joint of 7075-T6 aluminum alloy. The fine texture microstructure of base metal has been observed and many second-phase particles are found to uniformly distribute at the grain boundaries or inside the grain in base metal (Fig.2a). Affected by welding thermal cycle, grains and precipitates coarsen in HAZ, as seen in Fig.2b. A dendritic microstructure is found in the center of fusion zone, as shown in Fig.2c, which is due to the high cooling rate. The microstructural gradient in the laser-MIG hybrid welding method could influence the mechanical performances of welded joint, especially the fatigue performance.

2.2 *In-situ* observation of fatigue crack initiation and propagation

Fatigue damage in metals mainly includes the process of the initiation and propagation of micro-cracks. Fatigue crack initiation and propagation behaviors of base metal and laser-MIG hybrid welded joint of 7075-T6 aluminum alloy are displayed in Fig.3 and Fig.4, respectively. Fig.3 illustrates a typical case of fatigue micro-crack initiation and propagation behavior of base metal (loading direction is parallel to rolling direction) under the applied loading of $\sigma_{\max}$=490 MPa. Fig.3a shows that there is no crack on the surface of plate specimen. From Fig.3b, it is observed that the first fatigue crack (marked as 1) appears as the cyclic number reaches 73713 cycles. This cyclic number is defined as fatigue crack initiation lifetime (N_i). With the increase of cyclic numbers, as shown in Fig.3c, multiple micro-cracks initiate at the immediate vicinity of the second phase particles (marked as 2 and 3). Then the fatigue

Table 1 Chemical composition of 7075-T6 and wires ER5356 (wt%)

Alloy	Zn	Mg	Cu	Ti	Mn	Cr	Fe	Si	Al
7075-T6	5.54	2.43	1.30	0.05	0.10	0.19	0.25	0.20	Bal.
ER5356	0.10	4.80	0.10	0.12	0.15	0.10	0.40	0.20	Bal.

Table 2 Parameters of laser-MIG hybrid welding

Power/kW	Current/A	Voltage/V	Touch speed/$\mathrm{m\cdot min^{-1}}$	Filler speed/$\mathrm{m\cdot min^{-1}}$	Defocusing distance/mm
2.9	110	18	2.5	6.5	-1