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New technique of skin embedded wire double-sided laser beam welding

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A R T I C L E I N F O

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A B S T R A C T

In the aircraft industry, double-sided laser beam welding is an approved method for producing skin-stringer T-joints on aircraft fuselage panels. As for the welding of new generation aluminum-lithium alloys, however, this technique is limited because of high hot cracking susceptibility and strengthening elements' uneven distributions within weld. In the present study, a new technique of skin embedded wire double-sided laser beam welding (LBW) has been developed to fabricate T-joints consisting of 2.0 mm thick 2060-T8/2099-T83 aluminum-lithium alloys using eutectic alloy AA4047 filler wire. Necessary dimension parameters of the novel groove were reasonably designed for achieving crack-free welds. Comparisons were made between the new technique welded T-joint and conventional T-joint mainly on microstructure, hot crack, elements distribution features and mechanical properties within weld. Excellent crack-free microstructure, uniform distribution of silicon and superior tensile properties within weld were found in the new skin embedded wire double-sided LBW T-joints.

1. Introduction

Aluminum-lithium alloys are characterized by their low density, high strength and elastic modulus, excellent properties of anti-fatigue crack growth and corrosion resistance, improved ductility and toughness, and superb damage tolerance [1–3]. Since the first and second generations of Al-Li alloys presented some other characteristics that were found to be undesirable by aircraft manufacturers, with the progress of technology however, the third generation Al-Li alloys have received much attention for weight savings of aircrafts due to their more outstanding comprehensive performance than previous models. Among them, relatively new Al-Li alloys AA2060 and AA2099 are more promising candidates for fuselage panels of jetliners [4–7].

In Airbus Germany, double-sided laser beam welding (LBW) of skin-stringer T-joints in lower fuselage areas partly instead of using the dominant riveting technique has led to a certain reduction of aircrafts' weight. As already reported, T-joints composed of high strength Al alloys like AA2xxx, AA6xxx and AA7xxx alloys have been welded successfully without crack [8–11]. However, hot cracking sensitivity — one of Al-Li alloys typical weldability problems has threatened double-sided LBW further application greatly. What's worse, J. Enz et al. [12] found that, in compare with the inhomogeneous distribution of Li within the weld, the local loss of Si during welding caused hot cracking, whose influence on the mechanical properties of welds was supposed to be greater. Furthermore, it seemed difficult to improve elements' uneven distributions effectively only by changing the welding parameters.

In the present work, a new technique of skin embedded wire double-sided LBW was introduced to solve recent problems of hot cracking and elements' inhomogeneous distributions. In order to change the way of filling material reasonably, a special arc groove was designed and machined on the skin panel so that the wire could be filled into the skin before welding. With the combined function of embedding wire within the skin before welding and double-sided filling wires during welding, a crack-free T-joint with more uniform distribution and higher content of Si could be obtained.

2. Materials and experimental procedure

2.0 mm thick Al-Li 2060-T8 laminated panels (600 mm×150 mm) and 2.0 mm thick Al-Li 2099-T83 extruded profiles (600 mm×28 mm) were used for the skin and stringer components, respectively. These wrought Al-Li alloys were especially developed for the aircraft industry by Alcan Inc., in particular for the lower shell fuselage applications [13]. The filler wire used was a commercially available eutectic alloy AA4047 wire of 1.2 mm in diameter produced by Maxal Inc. Chemical compositions of base metals (BMs) and filler wire are listed in Table 1.

The skin embedded wire double-sided LBW involves several steps: pre-processing arc groove, embedding wire, and at last the double-sided LBW. Firstly, in pre-processing arc groove step, to avoid the generation of crack defect, an arc groove was accurately processed according to the special dimensional design. Critical sizes of the groove are illustrated in Fig. 1a. Secondly, in embedding wire step, AA4047

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Table 1
Chemical compositions of the base metals and filler wire (wt%).

Material	Cu	Si	Li	Zn	Mg	Mn	Zr	Ag	Al
2060	3.9	0.02	0.8	0.32	0.7	0.29	0.1	0.34	Bal.
2099	2.52	–	1.87	1.19	0.497	0.309	0.082	–	Bal.
4047	< 0.01	11.52	–	0.001	0.01	0.01	–	–	Bal.

wire was embedded into the groove by a clamping roller, as shown in Fig. 1b. Lastly, in the double-sided LBW step, the stringer was erected on the embedded wire on the skin by a mechanical clamping device. As depicted in Fig. 1c, the two fiber laser beams should be focused symmetrically onto two opposite positions along the stringer, respectively. The filler wire and shielding gas were delivered on the same plane as the laser beam and held at an angle of approximately 20° to the stringer in the leading and trailing directions, respectively. The adopted welding parameters are given in Table 2. In the last step, the new designed skin-stringer T-joint with embedded AA4047 wire was welded using two 6-axis industrial robots (KR-16W, KUKA Robot Group, Germany) which were connected to two 10 kW fiber lasers (YLS-10000, IPG Photonics Corp., Germany) and two wire feeders (KD-4010, Fronius International GmbH, Austria), respectively. The fiber lasers with an emission wavelength of 1.07 µm can deliver in continuous wave (CW) mode. The laser beam passed through a focusing mirror of 192 mm focus length and was finally focused as a spot of 0.26 mm in diameter. For the purpose of comparison, conventional double-sided LBW was additionally performed. The same welding configuration and parameters were also adopted as for the double-sided LBW without embedding wire.

After welding, welds' outer appearance and inner metallographic structure were detected by two optical microscopes (OLYMPUS SZX12 and OLYMPUS GX71). Selected welds were further analyzed by a scanning electron microscope (SEM, HITACHI S-3400N) on unetched microsections, and several positions within the weld zone were chosen to measure their local element distributions by an energy-dispersive X-ray spectroscopy (EDS) fixed on SEM, as located in Fig. 2. Precipitation phases' compositions were investigated by an X-ray diffraction apparatus (XRD, BRUKER D8 ADVANCE) and a differential scanning calorimetry facility (DSC, NETZSCH STA 449 F3).

The local mechanical properties within the weld zone were tested at a strain rate of 0.5 mm/min using an INSTRON-5569 universal testing machine. The 1.0 mm thick flat specimens according to ASTM E8/E8M-13a were extracted within the welds by an electrical-discharge machining and were parallel to the welding direction, as shown more detailed in Fig. 3.

Both of the skin embedded wire and conventional double-sided LBW T-joints were tested by X-ray nondestructive testing with a range of 200 mm and an angle of 45° between the skin panel and X-ray path. The X-ray negatives were transformed into digital images by scanning apparatus, and finally the pore defect characteristics were all extracted by the MATLAB software on computer.

Table 2
Welding parameters of the skin embedded wire double-sided LBW for T-joint.

Welding parameters	Values
Laser power (P)	3.2 kW
Welding velocity (V_w)	10 m/min
Wire feeding rate (V_{fw})	4.5 m/min
Incident beam angle (θ)	22°
Wire feeding angle (α)	22°
Wire feeding angle (β)	20°
Wire extension	8 mm
Focal position	Specimen surface
Shielding gas	Argon
Shielding gas flow rate	15 L/min

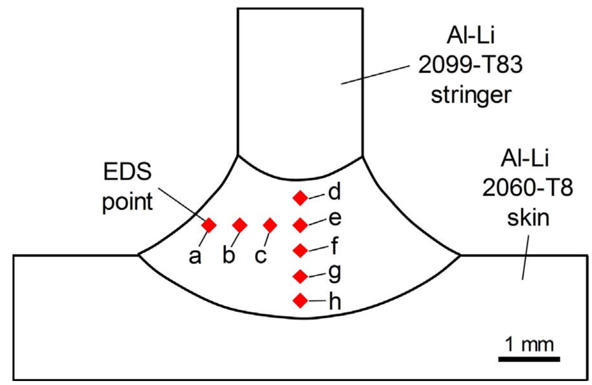

Fig. 2. Sketch map of the measuring points for the EDS analysis.

3. Results and discussion

3.1. Macro- and microstructures of the welds

Typical macroscopic appearance of the skin embedded wire double-sided LBW T-joint is shown in Fig. 4. In contrast with the macrograph of conventional double-sided LBW T-joint in Fig. 4b, most importantly, no hot crack could be observed on the skin embedded wire double-sided LBW T-joint, and no tiny spatter mark was found which means a more stable droplet transition during welding, as shown in Fig. 4a. Besides, some dark blocky deposits were observed on the weld of skin embedded wire double-sided LBW, and these deposits probably originated from the convergence of Si within the pool and coagulated mainly on the weld surface.

Cross-sections of the entire welds welded by the conventional and skin embedded wire double-sided LBW are shown in Fig. 5, respec-

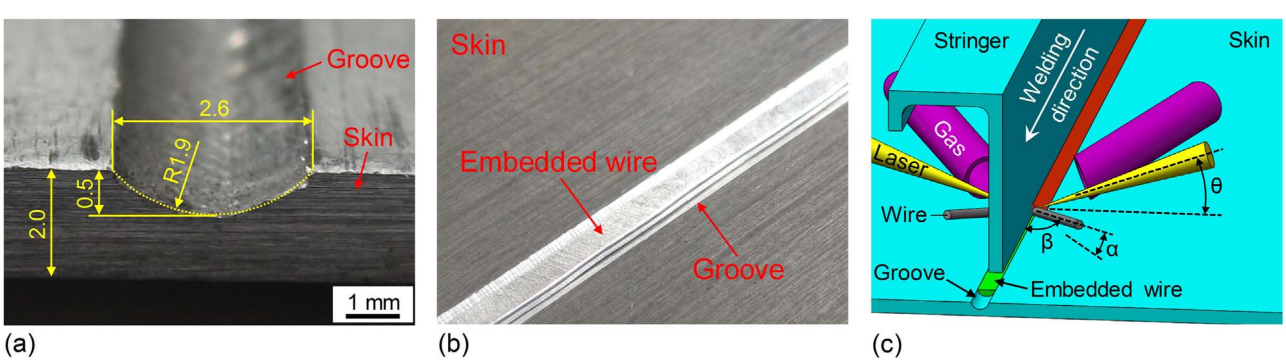

Fig. 1. Physical dimensions of the arc groove (a); embedded wire inside the groove (b) and used configuration for the skin embedded wire double-sided LBW of T-joints (c).