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Double-sided fiber laser beam welding process of T-joints for aluminum aircraft fuselage panels: Filler wire melting behavior, process stability, and their effects on porosity defects

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ABSTRACT

Aluminum alloy T-joints for aircraft fuselage panels were fabricated by double-sided fiber laser beam welding with filler wire, and the influence of the wire feeding posture on the welding process stability was investigated. A CMOS high speed video system was used to observe the wire melting behavior and the weld pool dynamics in real time during the welding process by using a bandpass red laser with an emission wavelength of 808 nm as backlight source to illuminate the welding zone. The weld porosity defects were analyzed by X-ray radiography. The effects of wire feeding posture on the wire melting behavior, process stability, and porosity defects were investigated. The experimental results indicated that three distinct filler material transfer modes were identified under different wire feeding positions: liquid bridge transfer mode, droplet transfer mode, and spreading transfer mode. The liquid bridge transfer mode could guarantee a stable welding process, and result in the lowest porosity. Compared with wire feeding in the leading direction, the process was not stable and porosity increased when wire feeding in the trailing direction. Increased in the wire feeding angle was disadvantage for pores to escape from the weld molten pool, meanwhile, it made the welding process window smaller due to increasing the centering precision requirement for adjusting the filler wire.

1. Introduction

Riveting is the dominant joining technology for the aluminum alloy skin-stringer structure in aircraft manufacturing [1]. The main drawbacks of the riveting process are the low productivity and high cost. Moreover, it is an extremely mature technology in which it is difficult to make further development [2–4]. Driven by improved production efficiency and weight reduction, double-sided fiber laser beam welding technology was first proposed within Airbus Germany to substitute the riveting for the aluminum alloy skin-stringer connection [5–7]. Up to now, this innovative technology has already been introduced successfully in the series production of the Airbus A318 and A380, and proved beneficial to both improve production efficiency and reduce weight of the modern aircraft [2,8,9].

With too many parameters and strict requirements for adjusting the three-dimension posture of the filler wire, laser beam welding with filler wire is usually considered to be a complicated process for industrial application, especially for welding process for the T-joint because of its special structure. Most of the published literatures have usually focused on the influence of different welding parameters on the microstructure characteristics and mechanical properties of the double-sided laser beam welded T-joints [10–13]. There are few of researchers who pay attention to the influence of wire feeding parameters on the wire melting behavior, process stability, and weld quality during laser bead-on-plate welding. For the sake of guaranteeing the process stability, it is necessary to have a strict control on the wire feeding position and direction [14,15]. Salminen [16] pointed out that the misalignment of filler wire in the welding direction to the laser beam optical axis influenced the melted wire transfer mechanism, and therefore affected the process stability. According to the results of Syed [17], wire feeding in the leading direction was more conducive to ensure good weld formation and weld quality. Conversely, Xiao [18] indicated that welding with the trailing wire addition was more advantageous to the process stability than with the leading wire addition. A steep wire feeding angle reduced the reflection of the incident laser energy. However, increased difficulties occurred when adjusting the filler wire since very small displacements would lead to the beam's point of contact with the wire, which may result in an unstable welding process [19].

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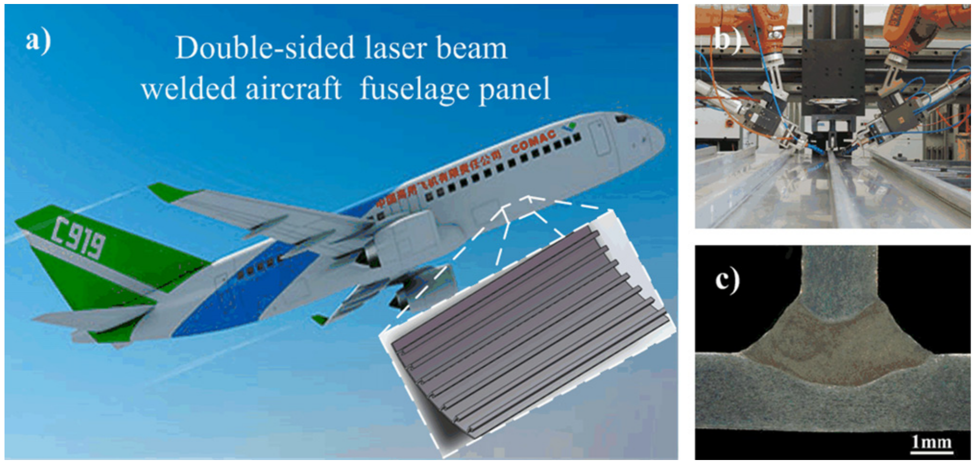

Fig. 1. Double-sided laser beam welded panels in lower fuselage of C919: (a) application location, (b) double-sided laser beam welding system, and (c) cross section of the welded T-joints.

During manufacturing of the aircraft fuselage, our previous experimental results demonstrated that it was extremely difficult to guarantee the stability of welding process due to the limitations of the skin-stringer structure and long welding path (> 2000 mm), as shown in Fig. 1. Therefore, it is imperative to investigate the effects of wire feeding postures on the process stability of double-sided fiber laser beam welding for T-joints to successfully utilize this innovative technology in the production of the C919 (the first China-made large passenger aircraft). Furthermore, laser beam welding with filler wire has also been used in some other fields, such as car manufacturing [16], direct metal deposition (DMD) process for single and multilayered clad/parts [19], design high power active – MMI SLED [20–22].

In the present work, the process of double-sided fiber laser beam welding for T-joints was observed in real time by a high speed video system. The effects of wire feeding position, wire feeding direction, and wire feeding angle on the wire melting behavior and process stability were studied. The weld porosity defects under different wire feeding postures were also discussed.

2. Materials and experimental procedure

2.1. Materials

Laminated panels (500 mm × 60 mm) of 1.8 mm thick AA6156-T6 and extruded profiles (500 mm × 28 mm) of 1.8 mm thick AA6056-T4 were used for the skin and stringer components, respectively. These wrought aluminum alloys were developed for the aircraft industry by Alcan Inc., especially for the lower shell fuselage applications [23]. The classical T-joint configuration is depicted in Fig. 2. The filler wire used was a commercially available eutectic alloy AA4047 wire of 1.2 mm in diameter produced by Maxal Inc. Their chemical compositions are given in Table 1.

Before welding, the pretreatment of the skin and stringer materials was processed with chemical cleaning followed by swashing with fresh running water and finally drying in a drying furnace.

2.2. Experimental method and setup

The welding experiments were carried out with a combiner of two 10 kW fiber lasers (YLS-10000, IPG Photonics Corp., Germany) and two wire feeders (KD-4010, Fronius International GmbH, Austria), which were controlled by two industrial robots (KR-16W, KUKA Robot Group, Germany). The fiber lasers with an emission wavelength of 1.06 μm can deliver in continuous wave

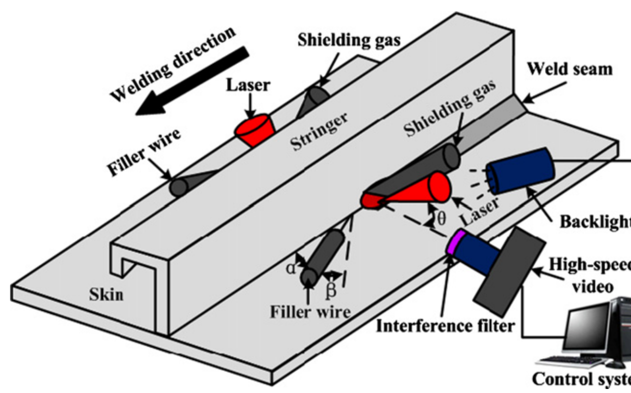

Fig. 2. Schematic diagram of the experimental system setup for process observation during fiber laser beam welding with filler wire (not to scale).

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

Materials	Mg	Si	Cu	Mn	Zn	Fe	Al
AA6056	0.9	1.0	0.8	0.6	0.4	–	Balance
AA6156	0.9	1.0	0.9	0.6	–	–	Balance
AA4047	0.01	11.52	< 0.01	0.01	0.001	0.2	Balance

(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.

In the double-sided welding process, the weld seams between the lower skin panel and the upper stringer were obtained simultaneously from both sides of the stringer. As shown in Fig. 2, to achieve a common weld molten pool, the two fiber laser beams should be focused symmetrically onto two opposite positions along the stringer, respectively. To stabilize the welding process, 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. The filler wire was fed into the weld molten pool either in the leading direction or in the trailing direction. The adopted welding parameters are shown in Table 2.

A CMOS CR5000 × 2 high speed video system (Optronis GmbH, Germany) was used to observe and record one-sided welding phenomena during the welding process. The observation was focused on the behavior of wire melting, metal transfer as well as weld formation. The computer-based high speed video was obliquely