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Stitch welding of Ti−6Al−4V titanium alloy by fiber laser

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Abstract: Stitch welding of plate covered skeleton structure of Ti−6Al−4V titanium alloys has a variety of applications in aerospace vehicle manufacture. The laser stitch welding of Ti−6Al−4V titanium alloys was carried out by a 4 kW ROFIN fiber laser. Influences of laser welding parameters on the macroscopic geometry, porosity, microstructure and mechanical properties of the stitch welded seams were investigated by digital microscope, optical microscope, scanning electron microscope and universal tensile testing machine. The results showed that the three-pipe nozzle with gas flow rate larger than 5 L/min could avoid oxidization, presenting better shielding effect in comparison with the single-pipe nozzle. Porosity formation could be suppressed with the gap between plate and skeleton less than 0.1 mm, while the existing porosity can be reduced with remelting. The maximum shear strength of stitch welding joint with minimal porosity was obtained by employing laser power of 1700 W, welding speed of 1.5 m/min and defocusing distance of +8 mm.
Key words: Ti−6Al−4V titanium alloy; fiber laser; stitch welding; welding parameter; porosity

1 Introduction

Due to their high specific strength, excellent corrosion and high temperature resistance, titanium alloys have been recently used in the aerospace, automotive, medical devices and also military industries [1−3]. Conventional welding procedures can be used for joining Ti−6Al−4V sheets, but the lower material thermal conductivity and the stress produced by large heat input during welding usually lead to deformation of workpiece [4]. Nevertheless, laser welding presents particular suitability for welding of Ti−6Al−4V due to its high energy concentration, easy to realize automation and rapid processing capability [5]. A comparative study of gas tungsten arc welding, laser welding and electron beam welding of Ti−6Al−4V alloy has been researched by BALASUBRAMANIAN et al [6]. It has been reported that laser welds possess the narrowest fusion zone and heat affect zone.

For laser welding, parameters such as welding speed, output energy and focal position, directly influence the quality of welding joints. It is possible to control the penetration depth and geometry of the laser butt weld bead by precisely controlling the laser output parameters [7]. LIU et al [8] examined the joint strength of titanium using several levels of laser output energy. Due to the high rate of laser beam absorption and low thermal conductivity of titanium, a greater penetration depth has been obtained with increasing the output energy, under suitable condition, joint strength similar to that of parent metal could be achieved. CAO and JAHAZI [9] investigated the effects of laser welding speed on butt joint morphology and mechanical properties of Ti−6Al−4V. The result shows that the fusion zone area and underfill depth decrease with increasing welding speed, joints without or with minor defects can be obtained, and weldments have slightly higher joint strength but lower ductility compared with parent metal. Previous research has come to similar conclusions by WANG et al [10].

Since titanium is highly reactive with nitrogen, oxygen and hydrogen at high temperature, leading to lattice distortion or cracks in welds, gas shielding is very important for the titanium alloys in laser welding [7]. Usually, shielding gas such as argon or helium is brought

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in by means of a steel tube to the impact zone. The simulation results indicated that the assist gas rate should be larger than 7.5 L/min [11]. COSTA et al [12] have shown that, the Ti−6Al−4V weld beads are free of oxides when argon is used as shielding gas at a flow rate of 13 L/min. Meanwhile, the shielding gas can effectively avoid welding plume formation and then improve the keyhole stability [13]. However, the shielding gas in the molten pool that cannot escape before solidification will form porosity [14].

Up to now, a lot of investigations on laser welding of Ti−6Al−4V alloy have mainly concentrated on butt welding method, and laser stitch welding of Ti−6Al−4V alloy has been seldom reported. However, stitch welding joints of Ti−6Al−4V alloy have a variety of applications in aerospace vehicle manufacture, and the welding joints properties are closely associated with the machine's performance. In our work, Ti−6Al−4V plate and skeleton sheets with thickness of 1.6 and 6 mm were stitch welded by fiber laser welding. In order to get good quality of Ti−6Al−4V stitch welded joints, the effects of laser welding parameters (gas protection method, gas flow rate, laser power (*P*), welding speed (*v*), defocus distance (*f*), remelting times and gap between plate and skeleton) on welded seam morphology, porosity, microstructure and mechanical properties were investigated systematically.

2 Experimental

The annealed plates of the as-cast ZTC4 titanium alloy (105 mm × 15 mm × 6 mm) and TC4 titanium alloy (100 mm × 80 mm × 1.6 mm) were selected separately as skeleton and plate materials and their chemical compositions were shown in Table 1. A high-power (4 kW) ROFIN fiber laser equipped with YW52 laser and ABB IRB 4600 six-axis robot were employed. A collimation lens, a focal lens and an optical fiber were used to produce a focal spot of approximately 0.4 mm.

Table 1 Chemical compositions of titanium alloy (mass fraction, %)

Material	Al	Fe	Mo	V	C	Ti
TC4	5.18	4.16	0.026	4.01	≤0.10	Bal.
ZTC4	3.87	5.57	0.029	3.97	≤0.10	Bal.

To avoid reaction between the molten metal and the atmospheric moisture and oxygen, the welded seams were carefully shielded with pure argon gas. Two kinds of welding covering gas nozzles were designed, as shown in Fig. 1. One consisted of a single pipe (see Fig. 1(a)) and the other was combined with three pipes (see Fig. 1(b)). The first pipe was mainly to provide gas to prevent joint oxidation and eliminate the influence of plasma shielding during the welding process, while the other two were mainly to prevent weld oxidation during the process of welding and cooling. Both of the two nozzles were 2 mm away from the surface of plate, and the angle between blowing direction and welding direction was 135°.

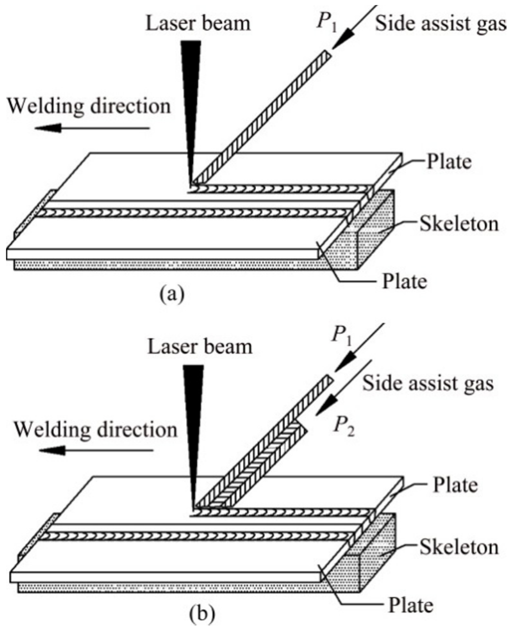

Fig. 1 Schematic diagrams of covering gas nozzles: (a) Single-pipe nozzle; (b) Three-pipe nozzle

In order to wipe off oxidation film and contamination, the surfaces of the plates were polished and cleaned with acetone prior to the clamping in weldment setup. Welding parameters such as gas protection method, gas flow rate, laser power, welding speed, defocusing distance, the gap between plate and skeleton and remelting times were investigated in this study to evaluate the effects on welding quality of lap joints.

For each welding condition, at least three weld cross-sections with four geometric parameters which had a great effect on the quality of the laser welding were analyzed to obtain weld dimensions, as shown in Fig. 2, where *B* represents the width of weld pool, *b* represents the connect width between plates, *H* represents the penetration depth of the welding and *a* represents the gap between plate and skeleton.

The quality of welded joints could be judged by the color of welded seam after welding. Welded seam with

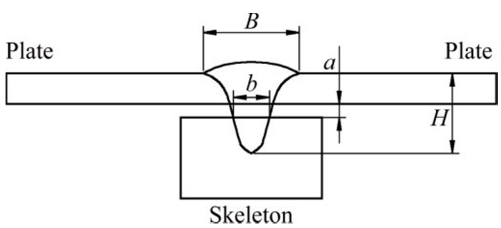

Fig. 2 Scheme of laser-welded cross section