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Short Communication

Microstructure and microhardness of fiber laser butt welded joint of stainless steel plates

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ABSTRACT

The butt welding of 304 stainless steel plates with thickness of 3 mm and 6 mm were achieved by YLR-6000 fiber laser under Ar protective gas. The weld appearance, microstructure, composition distribution and microhardness of welded joint were emphatically investigated. The results showed that the narrow and fully penetrated welded joint without marco-defects can be obtained with tightly focused 2 kW fiber laser power and 20 mm/s welding speed. The weld bead was smooth, and various microstructures typically formed at different zones of the welded joint. The fine columnar and equiaxed crystals existed in the edge and center of weld bead, respectively. Both were different with the microstructure of the stainless steel substrate. However, the composition distribution of the welded joint had no obvious changes. Furthermore, the superior microhardness of welded joint over the stainless steel substrate was mainly attributed to its finer microstructure.

1. Introduction

Stainless steel is a very important material in critical industrial technologies because of its excellent mechanical properties. In recent years, researchers have adopted many methods to further improve its surface or whole performances in order to fit for all kinds of adverse circumstances as far as possible [1–3]. Additionally, the joining of the separate stainless steel plates in some cases is also necessary to meet the actual needs. Welding is one of the most effective joining methods, which commonly includes arc welding [4,5], friction stir welding [6,7], induction welding [8], laser welding [9–12] and so on. By comparison, laser welding is an efficient and high-precision welding method known for its deep penetration (high depth-to-width ratio), high speed, narrow heat affected zone (HAZ), fine welding bead quality and low heat input per unit volume. Therefore, laser welding has been increasingly utilized in industrial manufacturing and has been caused particular research interest in welding various steel structures.

Among various lasers, CO_2 laser and Nd:YAG laser have been widely used as high-power laser heat sources for welding. However, with the mature and industrialization of fiber laser technology, a new generation of high power laser–fiber laser has obtained rapid development due to its advantages of high power, high beam quality and high efficiency to produce deep penetration welds at high welding speeds [13–15]. Hence, the application of fiber laser welding for metallic materials is being steadily increased. Miyamoto et al. [16] was the first one to realize the fiber laser welding of stainless steel foil at a limited output power of about 50 W. The limited laser power level also becomes a restriction for the welding of the thick plates. Recently, the fiber laser has been gradually used to weld the thick plates owing to the occurrence of kilowatt level laser power, showing a great potential to replace conventional CO_2 and Nd:YAG lasers. However, few attempts have been made in stainless steel plates welding with a high-power and tightly focused fiber laser beam so far. In addition, the microstructure and mechanical property of austenitic stainless steel joint welded by fiber laser are rarely reported. Thus, it is necessary to investigate the microstructure and mechanical property of the stainless steel joint after fiber laser welding.

In this paper, the type 304 stainless steel plates with 3 and 6 mm thickness are welded by a 6 kW high power fiber laser. The weld appearance, microstructure, composition distribution and microhardness of welded joint have been investigated in detail and compared with that of the stainless steel substrate. Moreover, the relevant mechanisms are discussed.

2. Experimental procedures

2.1. Material

The materials used in this study are type 304 austenitic stainless steel plates with thickness of 3 mm and 6 mm. The chemical composition is given in Table 1. The stainless steel plates are cut into

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Table 1
Chemical composition of the 304 stainless steel.

Element	C	Mn	P	S	Si	Ni	Cr	Fe
(wt.%)	0.049	1.04	0.021	0.007	0.58	8.66	18.20	Bal.

100 mm × 50 mm plates using wire cutting in the butt weld experiments. Before welding, the stainless steel surfaces and welding contact surfaces were polished by fine metallographic sandpaper and then cleaned by acetone to eliminate surface contamination.

2.2. Laser welding procedures

The laser equipment in this study is a 6 kW Yb-fiber laser system (YLR-6000) equipped with an ABB robot, and the experimental setup is shown in Fig. 1. The fiber laser wavelength is 1070 nm, the focal length is 250 mm and the fiber core diameter is 200 μm. Based on a series of pretests, the better welding parameters are selected to be the tightly focused 2 kW fiber laser power and 20 mm/s welding speed for obtaining the narrow and fully penetrated welded joint in this experiment. Additionally, the defocusing distance of laser beam is +5 mm, and the weld top surface is protected by shielding gas argon with flow rate of 5 l/min.

2.3. Microstructure observation and microhardness test

Metallographic methods are used to reveal the microstructure of the weld bead and stainless steel substrate. After welding, the samples are cut transversely from the welds by wire cutting, and then mechanically grinded and polished to obtain a good test surface, and finally etched by a solution of aqua regia (HCl: HNO_3 = 3:1) with an etching time of 10 s to reveal the microstructure. The microstructure is observed by scanning electron microscope and optical microscope. The composition distribution of welded joint is analyzed by the energy dispersive spectrometer (EDS).

Microhardness tests of the welded joint are performed using a HXD-1000TM type Vickers microhardness tester with applied load 200 g and loading time 15 s at room temperature, according to the ISO 22826:2005 standard [17]. Mircohardness tests are done in three lines as shown in Fig. 2: at the middle, 0.5 mm from the root and 0.5 mm from the top of welded joint. The distance between the measurements is 0.2 mm.

3. Results and discussion

3.1. Appearance of welded joint

Fig. 3 shows the top surface appearance of a relatively good welded joint at optimized laser welding parameters: 2 kW fiber laser power and 20 mm/s welding speed. It can be seen that the weld bead has smooth appearance and no obvious defects, such as crack and undercut. Additionally, the color of the weld bead surface is close to that of the stainless steel substrate, i.e., silver white color, which indicates the good shielding of the molten pool. While there are slight oxidation phenomena on both sides of the weld bead which attributes mainly to the metal oxidation when the protective gas Ar moves away.

Besides, the entire weld bead exhibits tiny compact fish scale shape structures, which distribute evenly consistent. However, there appear a bit of arc break flaws (see the arrow in Fig. 3). This phenomenon may be caused by the recoil pressure of laser plasma. During laser welding, the recoil pressure can push the liquid metal out of the molten pool to form spatter. Generally, the higher the laser power, the bigger the recoil pressure [18]. Therefore, the appropriate selection of the laser power is especially important. If the laser power is overlarge, the weld bead appearance will become poor and discontinuous.

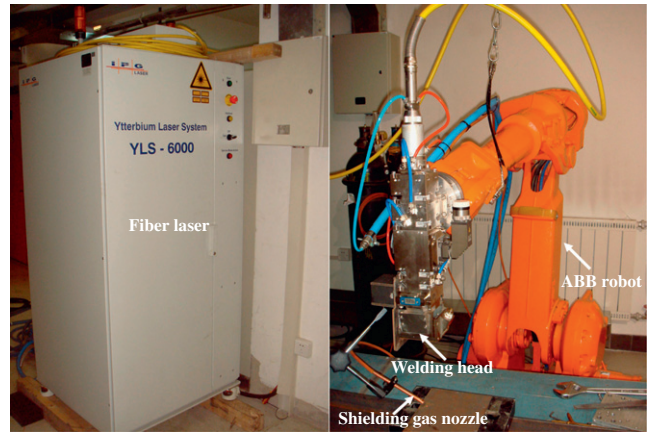

Fig. 1. Photograph of IPG 6 kW fiber laser and ABB robot.

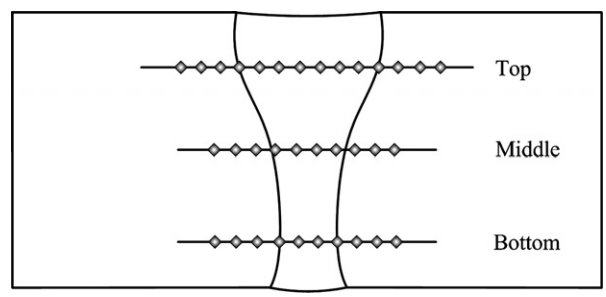

Fig. 2. Schematic drawing of microhardness test in welded joint.

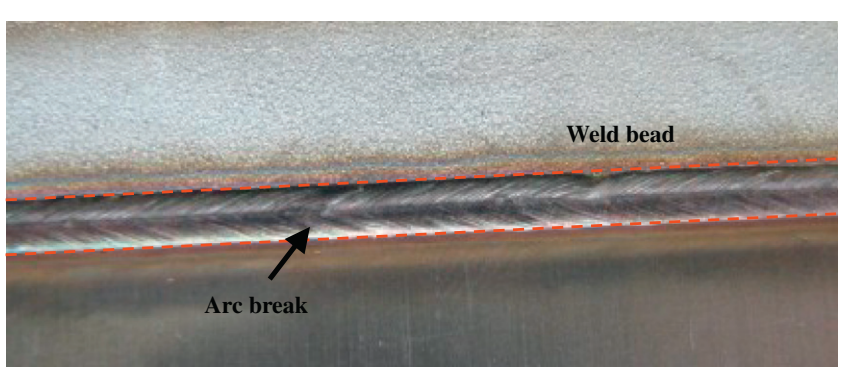

Fig. 3. Top surface appearance of welded joint at 2 kW fiber laser power and 20 mm/s welding speed.