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Residual stress, micro-hardness and tensile properties of ANSI 304 stainless steel thick sheet by fiber laser welding

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ABSTRACT

A fiber laser was chosen to weld the ANSI 304 stainless steel (ANSI 304 SS) sheets with a thickness of 5 mm. The effects of laser power, defocusing distance and welding speed on the weld appearances were investigated by the orthogonal test and the analyses on the appearances and properties of laser welds. Residual stress, micro-hardness and tensile properties of ANSI 304 SS welds were measured, and the cross section and surface morphologies were characterized by optical microscope (OM) compared with the two conventional laser (CO_2, Nd:YAG) welding methods. Results showed that ANSI 304 SS welds with good quality can be obtained if the appropriate fiber laser welding parameters were chosen. Tensile residual stresses of the fiber laser weld with the appropriate welding parameters were the lowest and micro-hardness and tensile properties were the highest among the three laser welding methods. In addition, the crystal solidification process induced by the fiber laser welding was schematically illustrated and systematically revealed.

1. Introduction

Welding is a fabrication or sculptural process that joins materials, usually metals or thermoplastics, by causing coalescence. In the past 40 years, many different welding methods can be used, including arc welding, submerged-arc welding, CO_2 gas shielded welding, metal inert-gas welding (MIG) or metal active-gas welding (MAG), tungsten inert-gas welding (TIG) and laser welding. However, there exist many disadvantages using conventional welding methods, such as large heat affected zone (HAZ) and fusion zone (FZ), high shrinkage, high residual stress, low welding speed, evaporative loss of alloying elements and distortion of welded joints [1–6]. Compared to these technologies with low efficiency, bad wind-resistance and easy-oxidability, laser welding has been becoming an important welding method because of high degree of automation and high production rate, and so it is widely used in industrial applications.

There are two kinds of the laser sources, CO_2 laser and Nd:YAG laser, for conventional laser welding. The wavelength of Nd:YAG laser is shorter than CO_2 laser, and has the stronger light absorption for the material surface. Beams of Nd:YAG laser propagate through lens or the fiber, while those of CO_2 laser propagate only do through lens. In addition, Nd:YAG laser has higher pulse energies and its size is smaller than CO_2 laser [7–9]. Fiber laser welding, as an emerging welding method, has been received attention in the recent ten years compared to CO_2 and Nd:YAG laser welding. The fiber laser with a maximum output power of 5–10 kW and even up to 50 kW was developed [10,11]. Due to high-power, high-beam quality and high-welding speeds, the fiber laser can product narrow and deep penetration welds of the thick metal sheet [12]. The fiber laser owns more stable beam quality and smaller focal spot diameter, which can supply higher power density easily when it is focused [13,14]. In addition, the fiber laser has good flexibility because it is easy to be controlled, so it can reach every position expediently where conventional laser sources can hardly reach [15]. Finally, the service life of the fiber laser is longer than any laser source.

As far as austenitic stainless steel is concerned, conventional laser methods often lead to low mechanical properties such as micro-segregation, precipitation of secondary phases, presence of porosities, solidification cracking, grain growth in the HAZ and loss of materials by vaporization due to its metallurgical changes [16–18]. As a result, it is necessary to introduce the fiber laser welding to weld austenitic stainless steel. High-quality weld depends on the laser welding parameters, such as the laser power (P), the welding speed (v), the defocusing distance (Δf) and the spot diameter (D) of the laser beam and the shielding gas. Up to now, there are few researches on the fiber laser welding of the thick sheet and mechanical and tensile properties of welds [19], flaw inhibition of welds [20], and numerical problems during the welding thermal process [21].

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In the present work, the ANSI 304 stainless steel (ANSI 304 SS) sheet with a thickness of 5 mm was welded using the YLS-4000 fiber laser (IPG, USA). A lot of trial runs were conducted to determine feasible working limits of the fiber laser welding parameters, and different combinations of the laser welding parameters were carried out to obtain the appropriate welding parameter combination. The welding quality of ANSI 304 SS thick sheet was inspected to identify working limits of the laser welding parameters. Subsequently, cross section morphologic observation, residual stresses, micro-hardness and tensile properties of ANSI 304 SS thick sheet with the appropriate fiber laser welding parameters were measured, analyzed and compared with the conventional laser (CO_2, Nd:YAG) welding methods. Combined with surface morphologies observed by optical microscope (OM) in different zones, the crystal solidification process induced by the fiber laser welding was also schematically illustrated and systematically revealed.

2. Experimental procedures

2.1. Experimental material and its mechanical properties

In the present experiment, the ANSI 304 SS sheet with a thickness of 5 mm was chosen as welding materials. The chemical composition (wt %) and mechanical properties of ANSI 304 SS material were shown in Table 1 and Table 2. The dimensions of the laser welding sample were shown in Fig. 1.

2.2. Laser welding process

The YLS-4000 fiber laser (IPG, USA) was used to weld the ANSI 304 SS thick sheet, and the YW 50 laser welding head (Precitec Germany) was mounted on an IRB 4400 robotic arm (ABB). The spot diameter of the laser beam was 0.27 mm with a focal length of 190 mm. The ultra-high mixed gas integrating helium (He) and argon (Ar) (mixing ratio was 1:1) was selected as the shielding gas. The flow rate of adding gas was 0.6 m^3/h in the condition of coaxial adding gas during the fiber laser welding. A schematic representation of the completed weld with the dimension of 80 mm × 100 mm × 5 mm is shown in Fig. 1. In order to obtain the better laser welding quality quickly and use less material, parameters such as laser power (P), the welding speed (v) and defocusing distance (Δf) were chosen to change.

And then, CO_2 and Nd:YAG laser welding methods were used to be compared with the fiber laser welding. In order to provide comparability among the three laser welding methods, the shielding gas was the mixed gas integrating He and Ar (mixing ratio was 1:1) with the flow rate of 0.6 m^3/h, the defocusing distance of −3 mm and the laser welding speed was 35 mm/s during CO_2 and Nd:YAG laser welding.

Table 1
Chemical composition of ANSI 304 stainless steel (wt%).

Composition	C	Mn	Cr	Mo	Ni	Cu	Si	Nb	Fe
Percent (wt.%)	0.06	1.54	18.47	0.30	8.3	0.37	0.48	0.027	other

Table 2
Mechanical properties of ANSI 304 stainless steel.

Tensile strength (N/mm^2)	Yield strength (N/mm^2)	Elongation (%)	Hardness (Hv)
520	205	40	200

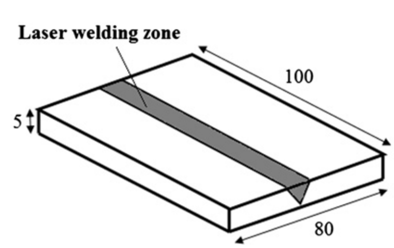

Fig. 1. Schematic representation of the laser welding sample (unit: mm).

2.3. Cross section and surface morphologic observation

After the fiber laser welding, the fiber laser welds at a welding speed of 35 mm/s with a laser power of 4000 W and a defocusing distance of −3 mm were chosen. The sections perpendicular to the

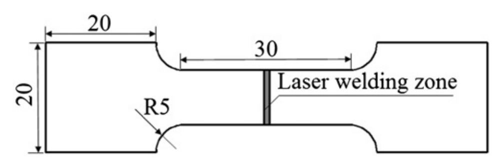

Fig. 2. The dimensions of the laser weld tensile sample (unit: mm).

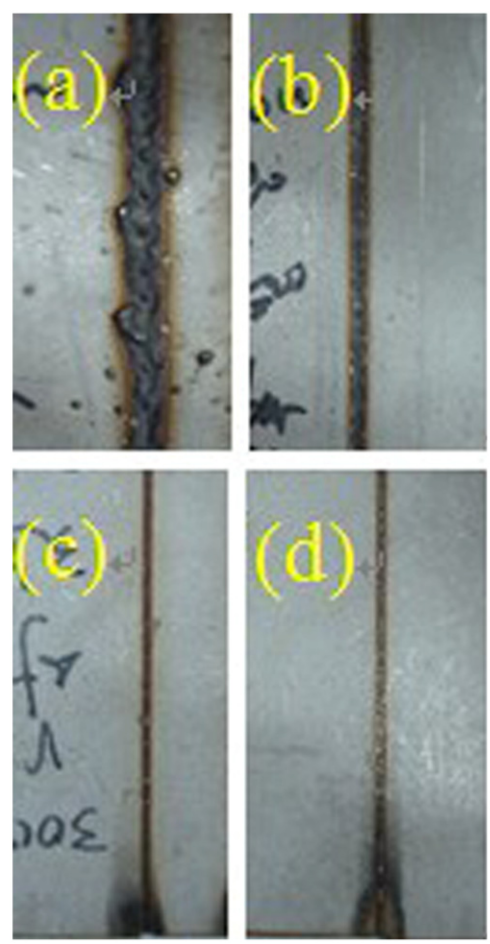

Fig. 3. Typical appearances of the fiber laser welds with a laser power of 3000 W. (a) the positive appearance at the welding speeds of 30 mm/s, (b) the positive appearance under welding speeds of 40 mm/s, (c) the reverse appearance at the welding speeds of 30 mm/s, and (d) the reverse appearance at the welding speeds of 40 mm/s.