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Underwater laser weld bowing distortion behavior and mechanism of thin 304 stainless steel plates

ZunYue Huang [a,1], Zhen Luo [a,b,*], Sansan Ao [a,1], YangChuan Cai [a,1]

[a] School of Materials Science and Engineering, Tianjin University, Tianjin, China
[b] Collaborative Innovation Center of Advanced Ship and Deep-Sea Exploration, Shanghai, China

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ABSTRACT

Underwater laser weld bowing distortion behavior and mechanism of thin 304 stainless steel plates are studied in the paper. The influence of underwater laser welding parameters (such as laser power, welding speed, defocusing distance and gas flow rate) on weld bowing distortion was investigated through central composite rotatable design and an orthogonal test. A quadratic response model was established to evaluate the underwater laser weld bowing distortion by central composite rotatable design and the order of the impacts of the welding parameters on weld bowing distortion was studied by an orthogonal test. The weld bowing distortion after welding was determined by the digital image correlation technique. The weld bowing distortion of in-air laser welding and underwater laser welding were compared and it revealed that the shape of the in-air and underwater laser welded specimens are the same, but the weld bowing distortion amount of in-air welding is larger than that of underwater welding. Weld bowing distortion mechanism was studied by the digital image correlation technique, and it was demonstrated that weld bowing distortion is associated with the welding plate temperature gradient during laser welding. The wider weld width also resulted in larger weld bowing distortion.

1. Introduction

Underwater welding has been widely used for repairing and joining components and structures that damaged in nuclear power plants or the offshore and sub-sea structures [1–4]. Compared with other underwater welding methods [2–4], underwater laser welding has many advantages, such as low heat input, easy to control adaptability and transfer energy [5]. In addition, Nd: YAG laser is delivered by an optical fiber [6] and easily transmitted to the components that are to be repaired and welded, which makes the repairing and welding more precisely [1]. In any fusion welding, weld bowing distortion due to rapid heating and cooling is not avoided and has bad impacts on subsequent assembly process and service life. And it is cumbersome and expensive to correct these distortions [7]. Thus, preventing or controlling the distortion during fabrication is desirable [7]. How to predict the distortion and remove the distortion during the fabrication process by providing an initial distortion in the negative direction have been widely studied by many scholars [8]. Mandal and Parmar [9] used a statistical method of two-level full factorial technique to develop mathematical models, and concluded that welding speed had a positive effect on angular distortion for single-pass or multipass welding. Murugan and Gunaraj [8] have developed mathematical models to establish a relationship between important process variables, namely, time between successive passes, number of passes, and wire feed rate, and angular distortion in structural steel plates joined with the multipass GMAW process. In addition, experimental regression equations to evaluate the bowing and angular distortions of 409M ferritic stainless steel after flux-cored arc welding was developed by Venkatesan et al. [7,10].

304 stainless steel sheets are mainly used in nuclear power plants for the excellent mechanical properties and corrosion resistance [11]. To the authors' knowledge, the relationships between the weld bowing distortion of AISI 304 stainless sheets underwater laser welding and the underwater laser welding parameters have not yet been reported before. And also, no mathematical response model was given out between the weld bowing distortion of AISI 304 sheets underwater laser welding and the laser welding parameters.

In this paper, a quadratic model was established to reveal relationships between the weld bowing distortion of 1 mm-thick AISI

* Corresponding author at: 31-291, School of Materials Science and Engineering, Tianjin University, No. 135 Yaguan Road, Tianjin 300354, China.

E-mail addresses: hzysmile@126.com (Z. Huang), lz_tju@163.com (Z. Luo), aosanmick@163.com (S. Ao), 18622265848@163.com (Y. Cai).

[1] Address: 31-291, School of Materials Science and Engineering, Tianjin University, No. 135 Yaguan Road, Tianjin 300354, China.

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304 stainless sheets fabricated by underwater laser welding and the laser process parameters (such as laser power (P), welding speed (v), defocusing distance (D) and gas flow rate (G). Central composite rotatable design was adopted to study the influence of the welding parameters on the weld bowing distortion. An orthogonal test was used to reveal the order of the impacts of the welding parameters on weld bowing distortion. The weld bowing distortion of in-air laser welding and underwater laser welding are also compared. The digital image correlation technique was adopted to measure the weld bowing distortion after underwater and in-air laser welding. The deformation process during in-air laser welding was determined by the digital image correlation technique to explore the weld bowing distortion mechanism. The influence of the weld width was also discussed in the paper.

2. Experimental procedures

2.1. Materials and method

Underwater laser welding and in-air laser welding were conducted with a JK2003SM type 2 kW continuous wave Nd: YAG laser equipped with a fiber optic beam delivery system. Materials used here were AISI304 plates with 1 mm thickness. The chemical composition of the base metal is shown in Table 1. Fig. 1 shows the underwater laser welding procedure. A water tank was set up for underwater welding, and a water curtain was used to form a local dry environment around the welding zone. Shielding gas was argon gas whose purity is 99.99%. During the welding, the curtain moved as the laser beam. Fig. 2 shows the weld distortion

Table 1
Chemical composition for AISI304 (unit: Wt.%).

C	Si	Mn	P	S	Cr	Ni	Cu	N	Fe
0.04	0.33	1.16	0.034	0.002	18.03	8.01	0.1023	0.0386	Bal.

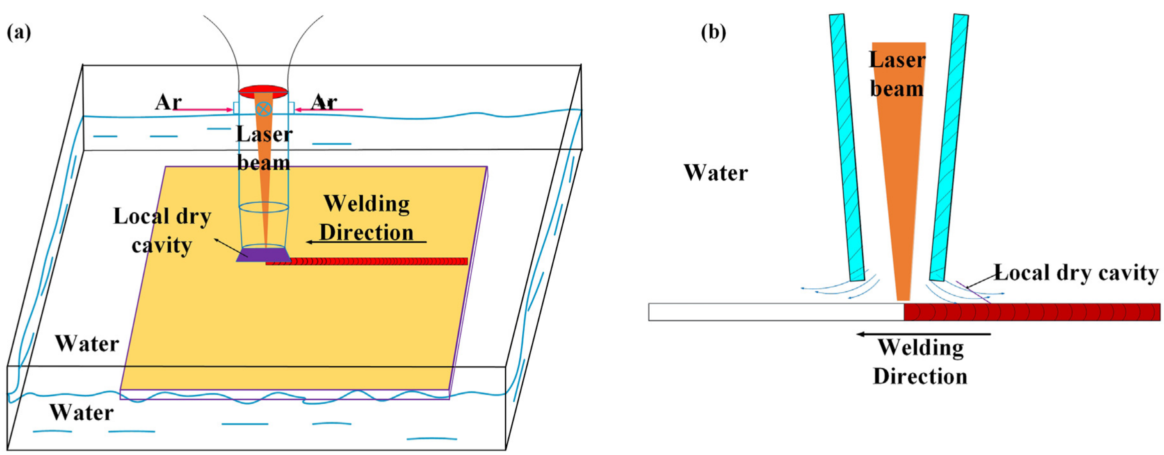

Fig. 1. Schematic of underwater laser welding device.

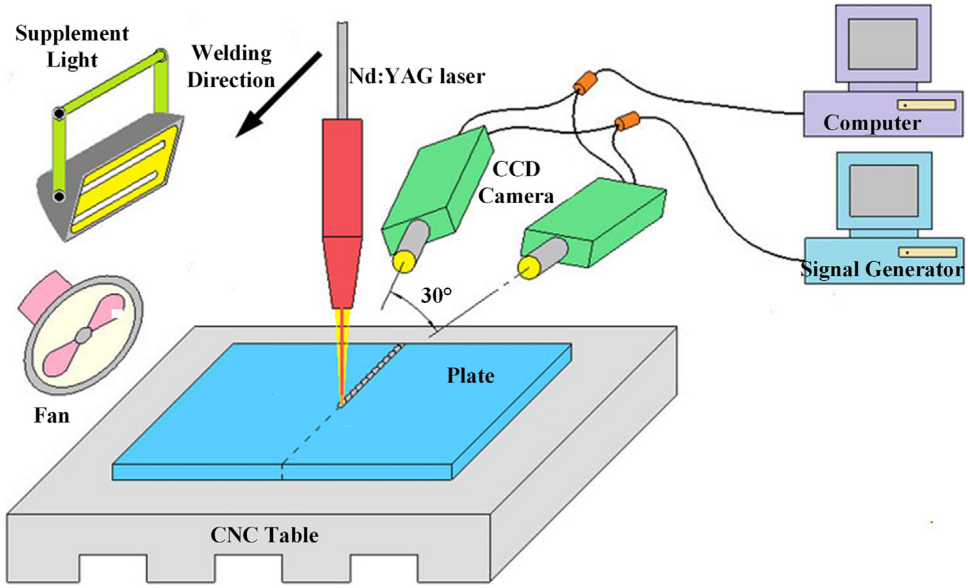

Fig. 2. Schematic of digital image correlation technique measuring the deformation process during in-air laser welding.