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Numerical simulation and experiment analysis of angular distortion and residual stress in hybrid laser-magnetic welding

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ABSTRACT

Hybrid laser-magnetic welding 316L steel with butt joint was investigated. The bottom width of the bead profile was broadened from 1.606 mm to 2.492 mm, grain size was homogenized, and austenitic content was also improved. Considering the influence of magnetic field on bead geometry, a new simplified heat source model was developed and used to simulate temperature distribution. Integrating the steady magnetic field with laser welding, angular distortion was reduced by 26.56%, the longitudinal residual stress was smoothed, transverse tensile stress was cut down from 199.1 MPa to 167.3 MPa, longitudinal residual plastic strain (−0.009) was homogenized to −0.007, and transverse residual plastic strain was decreased from −0.08 to −0.075. The laser-magnetic welding was useful to homogenize the weld of bead geometry, microstructure, angular distortion, residual stress and plastic strain.

1. Introduction

Welding performance of 316L steel has been studied by many researchers. The influence of welding parameters (heat input, cooling condition, shield gas and others) on bead geometry (Kocabekir et al., 2008), microstructure and hardness (Ahmadi and Ebrahimi, 2015), cryogenic toughness (Xiao et al., 2015), intergranular corrosion (Shaikh et al., 2002) and crack in alkaline environments (You et al., 2014), were researched by experiment method. Grey Taguchi methodology was applied to obtain the optimum parametric combination with a high weld quality (Ghosh et al., 2016). Underwater welding process of 316L steel was studied by Li et al. (2016), while the weld ability of 316L with other metals, such as titanium alloy (Tomashchuk et al., 2015), normalized and tempered steels (Alberta et al., 2014) and dual-phase steel (Moteshakker et al., 2016) and so forth, was also discussed.

Deformation and residual stress of welding 316L steel were also closely concerned based on finite element analysis. Computation accuracy of temperature field is the first step to obtain a credible result of welding deformation and residual stress. Double ellipsoidal heat source model was proposed by Goldak et al. (1984), and has been widely used to simulate temperature distribution. A new heat intensity function was developed by Wu et al. (2009) to compute temperature field for direct-diode laser welding with the characteristic of a rectangular output beam profile. Xu et al. (2013) built a hybrid heat source model to analyze residual stress and distortion of T-joint. Chukkan et al. (2015) developed simulation model to predict welding deformation and residual stress with different heat sources. Tchoumi et al. (2016) revealed the influence of tungsten inert gas welding speed on distortion. Elmesalamy et al. (2016) investigated on residual stress of narrow gap laser welding by numerical simulation and experiment validation using neutron diffraction method. Guirao et al. (2010) predicted the welding deformation of the vacuum chamber (vessel segment) with an optimized welding sequence. Jiang et al. (2012) attempted to decrease the joint residual stress using heat sink technology.

Magnetic field was applied to stir weld pool of laser welding in order to broaden bead geometry (Bachmann et al., 2014). Firstly, the objective of this paper is to analyze bead profile and microstructure of laser-magnetic welding 316L steel. Then, angular distortion and residual stress are investigated using numerical simulation and experimental verification, while a new simplified heat source model considering the actual bead shape is proposed. Lastly, the influence of steady magnetic field on the residual plastic strain is discussed.

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Table 1
Chemical components of 316L steel (wt.%).

C	Si	Mn	P	S	Cr	Mo	Ni	N	Cu	Fe
0.021	0.77	1.019	0.039	0.001	16.92	2.03	12.16	0.033	0.20	Bal.

2. Experiment analysis

2.1. Experiment procedure

Base metal was austentite steel 316L with chemical components shown in Table 1 (Rong et al., 2016a,b). Two plates with size of 100 × 50 × 3.8 mm were welded into butt joint by fiber laser welding. Fig. 1 showed the laser welding system. Optical beam was generated by ytterbium fiber laser IPG YLR-4000, and it was transmitted to the sample through optical fiber and welding head. A permanent magnet was placed under the sample, and its upper surface was parallel with the welding direction. Welding path was planned by the teaching programming method. Laser welding operation was completed using ABB robot.

The steady magnetic field was not considered in the first experiment (Case 1), but inversely in the second group (Case 2). Before welding, oil pollution on the plate surface was cleaned by acetone, and merging precision of each contact surface was guaranteed by milling process. Fiber laser power was 4 KW, welding speed was 0.02 m/s, defocus length was −5 mm, shielding gas was argon with flow rate of 1.5 m^3/h. Magnetic strength on the sample upper surface was 60 mT.

2.2. Measurement methods

Characteristics (microstructure, bead geometry, angular distortion and residual stress) for Case 1 and Case 2 were measured. One side of the welded sample was fixed, and cock height in the opposite side (namely angular distortion) was measured by the height vernier caliper (Rong et al., 2016a,b). Transverse residual stress along a transverse middle line on the top surface was measured by X-ray stress analyzer. The section sample was extracted by wire electrical discharge machining and eroded using aqua regia. Bead profile and microstructure were obtained by optical microscope. The size of bead shape was measured by CSM1 code.

2.3. Influence of steady magnetic field on bead profile and microstructure

The bead profile was given in Fig. 2. A full penetration has been produced in two welds of Case 1 and Case 2. As shown in Fig. 2(a), a typical cone shape was obtained without magnetic field. The shape (Fig. 2 (b)) was obviously changed when the steady magnetic field was considered. Joining the magnetic field, the weld upper width narrowed from 2.465 mm to 1.972 mm, but the bottom width broadened from 1.606 mm to 2.492 mm. Curve length of the weld side remained around 3.9 mm. The reason for the change of the bead shape was that more energy gathered at the bottom of the weld when weld pool was stirred by magnetic force.

As shown in Fig. 3(a), austenite and ferrite were included in the weld of laser welding (Case 1). When the steady magnetic field was joined into laser welding (Fig. 3(b)), segregation behavior was obviously reduced, grain size was homogenized, austenite content was also improved.

3. Numerical simulation process

Transient thermal-elastic-plastic finite element theory for predicting welding deformation and residual stress has been detailed in our previously published papers (Rong et al., 2016a,b). Thus, only the simulation framework and a novel heat source model were described in this section.

3.1. Computation framework

Simulation flow of temperature and mechanical field in laser welding 316L steel was shown in Fig. 4. Experiment results were applied to provide a basic support of building simulation process and verifying correctness of computation results. Sequential coupling method of temperature field and mechanical field was used because the effect procedure was unidirectional from the former to the latter. 3D model was built based on the actual experiment design, simulation results of transient temperature distribution

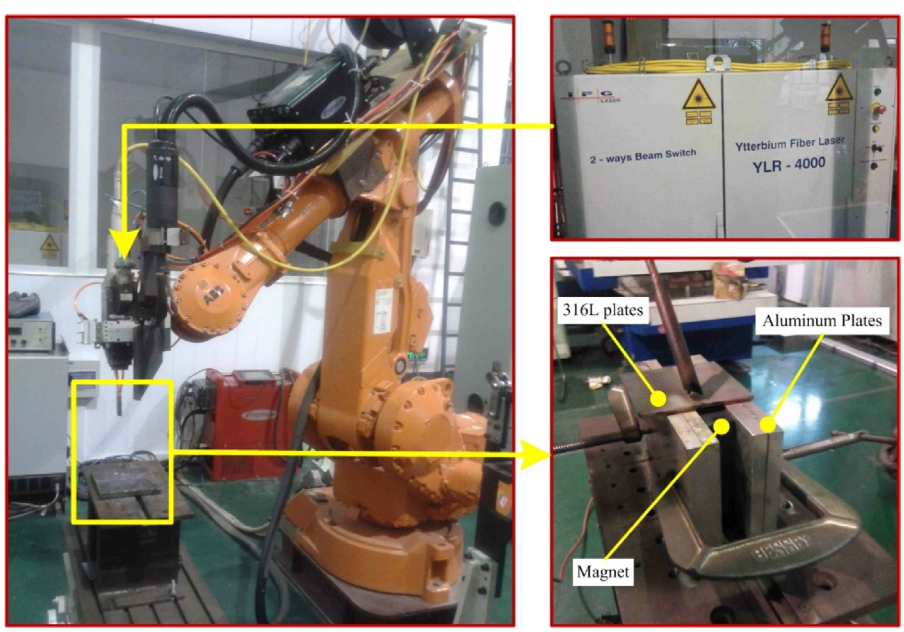

Fig. 1. Laser welding system.