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Arc characteristics and metal transfer behavior in narrow gap gas metal arc welding process

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ABSTRACT

During the constant-voltage welding machine employed welding process, a common phenomenon of arc attachment point moving from the bottom of the narrow gap to the sidewalls occurs, and metal transfer behavior appears greatly different. A mechanism that the arc inherent-self regulation combines the minimum arc voltage principle was proposed to elaborate the arc climbing up process along the sidewalls. The arc shape was approximately classified into three patterns by the change of arc conductive path, and the amount of the arc conductive path and its distributive symmetry determine the action of the electromagnetic force on the droplet as well as the metal transfer mode. As the number of the arc conductive paths increases, and the conductive paths distribute symmetrically, the necking process of the droplet detachment occurs more easily, and the metal transfer from globular mode to spray mode becomes more smoothly. Simulation results match the experiments and verify the mechanism proposed. In a constant-current welding power source adopted condition, the arc climbing up phenomenon cannot be observed, and a stable welding process is obtained.

1. Introduction

The steel thick walled plates, widely applied in shipbuilding, high-pressure vessels, etc., could be joined with kinds of welding approaches. For instance, Cao et al. (2011) joined 9.3 mm thick butt joints with the hybrid fiber laser-arc welding. Frank et al. (2010) adopted the fiber laser and gas metal arc welding (GMAW) to weld 16 mm and 20 mm thick plates of carbon steel. Gan et al. (2007) reported the friction stir welding of 12.7 mm thick L80 steel. Kiran et al. (2012) studied the effects of process variables on weld quality of HSLA steel using two-wire tandem submerged arc welding (SAW). For a conventional arc welding of the carbon steel thick plates, high-heat input to the work-piece may worsen the joint microstructure and properties, and the weld production requires longer welding time and filler metals that increase weld distortion. However, narrow gap gas metal arc welding (NG-GMAW) is considered as a high-efficient joining method for thick metal plates because of its lower equipment investment, lower heat input, easier operation, less filler metal, and thus less energy consumption, fewer deformation. Guo et al. (2011) investigated the metal transfer behavior in rotating arc narrow gap horizontal welding by changing wire rotating frequency. Xu et al. (2014) studied the microstructure and mechanical properties of high-strength low-alloy steel joints obtained with oscillating arc narrow gap GMAW. Cai et al. (2016) investigated the influences of different shielding gas composition on arc dynamics and metal transfer process.

Investigations point out that the arc characteristics and droplet transfer behavior in the GMAW process mainly determine the stability of welding process and the energy distribution which significantly affects the microstructure and various properties of joints. Comparisons of the conventional GMAW process indicate that the arc appearance of GMAW in the narrow gap is apparently compressed, and the droplet transfer process changes in a more unstable way. Thus, lots of weld defects (i.e., lack of fusion, porosity and slag inclusion) are more likely to generate without taking extra actions that change the arc shape and metal transfer modes. In order to stabilize the dynamic arc in the narrow gap and obtain a sound weld bead, several methods have been currently developed. Yang et al. (2009) developed a rotating arc system to stabilize the sagged weld pool in the narrow gap horizontal welding process. Wang et al. (2012) proposed a swing arc method to alter the arc attachment point and the staying time of the arc on the sidewalls for realizing high-quality narrow gap GMA welding with low cost. Xu et al. (2015) utilized response surface methodology to estimate and optimize the weld bead geometry in oscillating arc narrow gap all-position GMAW. Zhu et al. (2006) developed flux stripes to

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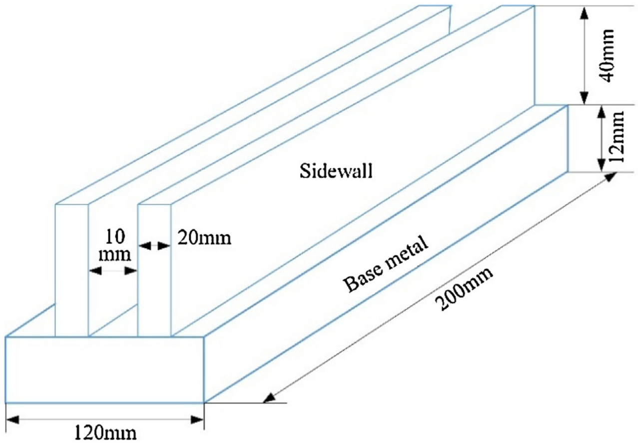

Fig. 1. Dimension of the work-piece.

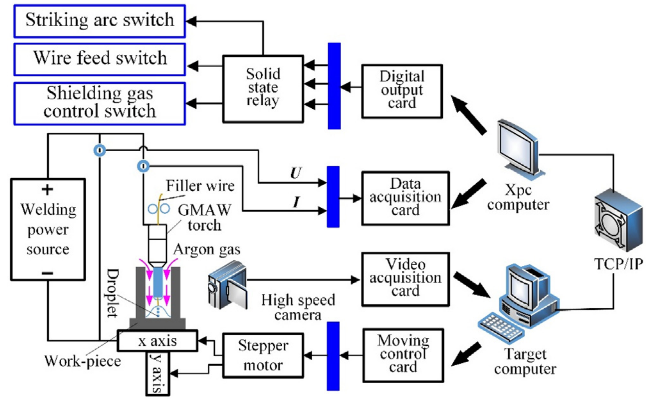

Fig. 2. Rapid prototyping experimental control system.

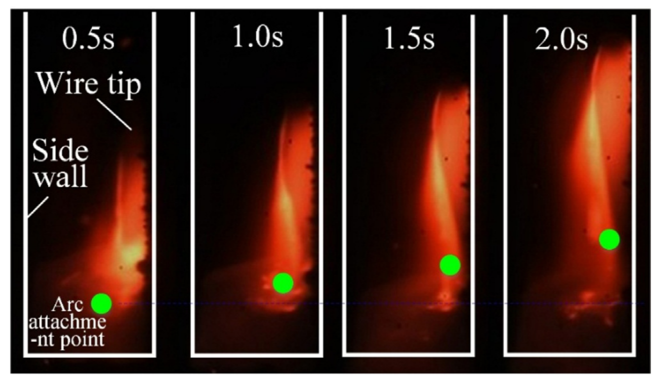

Fig. 3. Typical arc shape images under the CVPS condition.

construct the arc attachment in the ultra-narrow gap welding process and kept the full penetration of the sidewalls. Above-mentioned methods have partly improved the weld bead formation and weld quality. However, the metal transfer behavior and the weld bead forming mechanism in the narrow gap were not deeply studied. With the limit of the author's searching capability, studies on the dynamic arc behavior and metal transfer mechanism in the NG-GMAW process are rarely reported.

This paper focuses on the study of arc characteristics and droplet transfer behavior of the NG-GMAW, and theoretically elaborates on the formation mechanism of the different arc appearance and droplet transfer mode, which are compared with GMAW process. To this end, a high-speed sampling system is developed to capture the arc dynamics and droplet transfer produced by a constant-voltage power source (CVPS) and a constant-current power source (CCPS) respectively. During the CVPS employed welding process, a common phenomenon of the arc attachment point moving to the sidewalls is observed, and its evolvement rules are detailed. The arc model in the narrow gap is also established based on the change of the arc conductive path and is simulated using MATLAB/Simulink platform. This paper is organized by following: an experimental system in Section 2; analysis of the arc characteristics and metal transfer modes and its verification in Section 3 and the results in Section 4.

2. Experimental procedure

Q235 steel was used as the base and sidewall metal. ER50-6 wire with 1.2 mm diameter was used as the filler metal. Pure argon gas (99%) at a flow rate 10 L min^{-1} was utilized to protect the molten pool. The dimension of the work-piece is shown in Fig. 1. In the CVPS case, arc voltage was set 28 V. Welding speed was set 0.325 m min^{-1}, and the wire feed rate was changed from 4.3 m min^{-1} to 7.1 m min^{-1}. The curved wire that will feed in the narrow gap through a wire feeder was previously straightened, and the distance of the wire tip to the two sidewalls was accurately controlled. Welding assistive tools were set to minimize distortion of the weld. The schematic diagram of the experiment system is given in Fig. 2.

This system mainly consists of the welding control, rapid prototyping and video acquisition parts. In the welding control part, a Lincoln Electric® Idealarc® DC-400 CC/CV multi-process welder was applied to generate the heat source for fusing the work-piece and the filler wire, which has two output characteristics, including constant-voltage mode and constant-current mode. A semi-automatic Lincoln LN-7 wire feed machine was employed to control the wire feed speed in the narrow gap welding. The conventional GMAW torch was improved through grinding the width of contact tip and attaching the thin mica sheet on the ground contact tip. To this end, the torch amended can be easily stretched into the narrow gap and be avoided contacting with the sidewalls. Despite the limitation of the narrow gap, the shielding gas nozzle was removed. Hence, to protect the weld pool effectively, another two insulating heat pipes were mounted to the left and right side of the contact tip, and then the pure argon gas was input to the narrow gap. Lu et al. (2012) detailed the rapid prototyping control system as following three parts: the data exchanging section between the target and the host computers; the data-acquisition section; the control section. To acquire the images of arc shape and droplet in the NG-GMAW process, Olympus I-SPEED3 high-speed camera with an Olympus Camera Display Unit was employed. The camera with a speed of up to 15000 frames per second captures the images and stores in its on-board 8GB internal memory storage. Nikon AF-SDX VR 55–200 mm f/4-5.6G IF-ED lens with varying focal lengths was also used to acquire the arc shape and droplet images clearly. The GMA welding torch keeps stationary as the work-piece moves with a pre-setting rate during the entire welding process.

3. Results and discussion

3.1. Arc climbing up phenomenon

Lots of dynamic arc appearance and metal transfer images captured by the high-speed camera were carefully observed and comparatively analyzed with the normal GMAW process. Several typical arc appearance images were shown in Fig. 3. A common phenomenon that the arc attachment point moves to the sidewall is observed in the constant-voltage power source (CVPS) employed GMA welding process. The arc climbs up to the wire tip along the