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The energy distribution of electrode in hollow cathode centered negative pressure arc

Fan Jiang*, Zhaoyang Yan, Shujun Chen*, Zhenyang Lu

College of Mechanical Engineering and Applied Electronics Technology, Beijing University of Technology, Beijing 100124, China

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ABSTRACT

As a new type of welding heat source, hollow cathode centered negative pressure arc (HCCNPA) has evenly distributed energy density in the center of the arc and a higher energy gradient at the boundary in comparison with traditional gas tungsten arc (GTA). With these changes, the brightness of the cathode increased significantly, which is the effect of inner arc plasma on the hollow cathode. To better understand of this, in present study the measurements of energy distribution between anode and cathode in HCCNPA were performed respectively by calorimetric calculation. Experiments were conducted to evaluate the influence of welding parameters on heat distribution of HCCNPA, and the results were compared with conventional GTAW process. It was found that the application of negative pressure in the hollow cathode greatly modified the energy distribution between anode and cathode. Though the energy demand of maintaining a stable arc increased with the application of negative pressure which reflected as the increase of arc voltage, the total energy used to electrode became lower. In particular, the energy in cathode increased and that in anode decreased as the negative pressure applied, and these differences increase as the current and arc length increase. Otherwise, the application of negative pressure in the hollow made the result arc constrained, so the HCCNPA has a more evenly distributed energy density in the center and a higher energy gradient at the boundary in comparison with the conventional GTA, which would enable the development of high quality applications.

1. Introduction

Arc welding is one of the most efficient and economical methods for metals joining. Among various types of arc welding processes, gas tungsten arc welding (GTAW) controls the heat and mass (filler metal) independently, and offers high quality for welding. It has become the main welding process that used to aerospace and instrument industries [1,2]. Moreover, arc welding is a complex process that involves the interaction among different physical processes. Uneven heat distribution primarily influences the Heat Affected Zone (HAZ) around the weld pool. And this phenomenon leads to the generation of defects, which reduces the weld quality. That the improvement of welding heat source makes it suitable for high quality welding has been widely studied [3–9]. Such as, the innovative heat source of ultrasonic assisted GTAW, which has obvious advantages such as considerable penetration improvement [10,11]. The arcing-wire GTAW, which establishes a side arc to transfer part energy of the main arc to the filler metal, is developed to offer high deposition with low heat input [12]. Laser-hybrid GTAW has changed the energy distribution of the arc with the interaction between laser and electric arc [13–16]. Nevertheless, the aforementioned innovative heat sources adopt different techniques, but achieve the same result to change the arc energy distribution using other energy sources. The application of the hollow cathode centered negative pressure arc (HCCNPA) in the present work, another innovative variant of the GTAW process without other energy sources, increases the arc energy density to benefit welding.

As a newly modified welding heat source, HCCNPA can adjust the negative pressure in hollow cavity to control the arc heat and force. The principle diagram of the hollow cathode negative pressure arc is shown in Fig. 1. The arc is ignited in the atmosphere, through the mechanical pump exhausts the gas out of the hollow cathode; then a negative pressure is formed at the root of the hollow cathode. The intention of the hollow negative pressure is to absorb part arc plasma into the hollow cathode cavity to decrease the redundant energy both in and outside the desired heating region. The interaction between the hollow negative pressure and the atmosphere pressure around the arc make the arc

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* Corresponding authors.
E-mail addresses: jiangfan513@qq.com, jiangfan@bjut.edu.cn (F. Jiang), sjchen@bjut.edu.cn (S. Chen).

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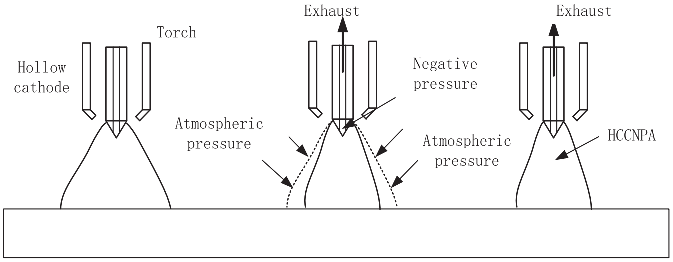

Fig. 1. The principle diagram of the hollow cathode negative pressure arc.

constrained, so as to increase the energy density of the arc and decrease the total energy of the arc.

The thermal-force behavior of welding arc can significantly affect the flow in the molten pool, weld morphology and microstructure [17,18]. A clear understanding of arc characteristics and heat transfer behavior is of great importance to obtain a better welding joint and improve the welding quality. In recent years, significant progresses have been made on modeling direct current GTA, including quantitatively analyzing the composition of the heat transfer to the anode [19–21]. Nevertheless, the heat transfer behavior of HCCNPA process still remains unclear. The authors have measured and analyzed the arc pressure distribution in this novel arc, and the characteristics of arc pressure by adjusting the negative pressure in hollow cavity were summarized [22]. It was found that the application of negative pressure in the hollow cathode greatly modified the pressure and energy both in anode and cathode. In addition, high arc energy reflected as the increase of arc voltage, but the energy used to heat anode became lower. In order to reveal the influence of negative pressure in hollow cathode, the arc and heat transfer behavior in HCCNPA process were quantitatively analyzed and described in this study.

2. Experiment setup

Fig. 2 shows the experimental schematic of the HCCNPA welding process. There are two pumps, two insulation cans with microcomputer temperature controller connected to the PC and insulation pipes compose the thermal insulation system. A high-speed photography device is used to observe the arc phenomenon during the welding process. A mechanical pump connected with the vacuum cavity is used to provide negative pressure for the hollow cathode. And in this paper, the hollow cathode is a 6.0 mm diameter tungsten electrode with a hollow of 1.0 mm diameter; and the diameter of solid cathode is 6.0 mm.

Table 1
Experimental parameters.

Cathode	Current (A)	Arc length (mm)	Negative pressure (MPa)
Hollow cathode	100	6	0.07
	150	5	0.06
	200	4	0.05
	250	3	0.04
	300	2	0.03

Table 2
Experimental parameters.

Cathode	Current (A)	Arc length (mm)
Solid cathode	100	6
	150	5
	200	4
	250	3
	300	2

The arc thermal output is the increased temperature of the circulating water connected to the anode and cathode, and the temperature is measured by a temperature sensor. During the welding process, the insulation cans connect the pump with cathode/anode, and all of the circular pipes are wrapped by the insulation device. The key of this test is to make sure the initial temperature of the water in the insulation cans is identical. The calculation formula of calorie is as follow:

$$Q = CM\Delta T \tag{1}$$

Wherein C is the specific heat of water, and the value is $C = 4.2 \times 10^3$ J/(kg °C), M is the quality of the water, ΔT is numerical value of the temperature increased in the insulation cans. The total arc thermal output as follow:

$$Q_{tal} = CM(\Delta T_1 + \Delta T_2) \tag{2}$$

Wherein ΔT_1 is the water temperature change in the insulation can 1, ΔT_2 is the water temperature change in the insulation can 2.

$$W = UIt$$

Wherein W is the energy of the arc during welding process, U is the voltage of arc, I is the welding current, and t is the measuring time.

$$Q_{lost} = W - Q_{tal}$$

Wherein Q_{lost} is the energy that neither use to anode nor to cathode.

The other main experimental parameters are electric current, arc length and the negative pressure in hollow cathode, as shown in

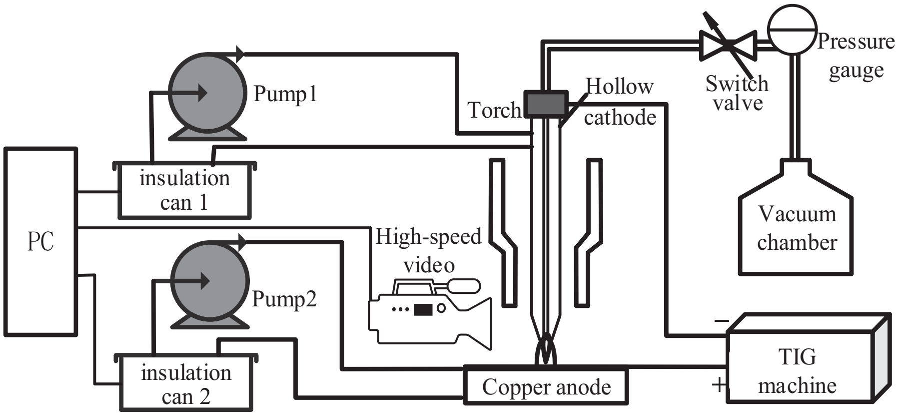

Fig. 2. The principle diagram of measure arc thermal.