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Coupling mechanism of laser and arcs of laser-twin-arc hybrid welding and its effect on welding process

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ABSTRACT

Laser-twin-arc hybrid welding, which combines the techniques of laser welding and twin-arc welding, is an emerging welding technology. In this study, synchronous information including spectral signal, high-speed photography and electrical signal is used to explore the physical interaction between the arcs and the laser of alternate burning in laser-twin-arc hybrid welding process, and the effect of the combined arc/laser heat source on the welding process was analyzed. The results indicated that the laser provides a conductive, stable plasma channel for the arcs, which can influence the arc shape, slow down droplet transfer, reduce resistivity and stabilize arcs. Electron temperature of hybrid arc plasma is from 7000 K to 17000 K, which is significantly influenced by laser parameters. The laser-twin-arc hybrid welding acquires deeper penetration and wider HAZ than with the twin-arc welding alone.

1. Introduction

The laser-arc hybrid plasma is important in material processing technology, especially for welding process [1]. Hybrid welding, which combines the techniques of laser welding and arc welding, was originally invented for combined laser-Tungsten Inert Gas (TIG) welding [2]. Most of the present hybrid welding processes are the combinations of laser with single heat source, e.g. laser–TIG, laser–plasma source, laser–MAG. A set of laser-twin-arc hybrid welding equipment was developed in 2001, in which three heat sources were placed in close contact with each other to produce a single high intensity energy source. This synergistic interaction of the three heat sources has been shown to get lower welding heat input per unit length, allow increased gap tolerances, as compared to laser-single arc hybrid welding, while retaining the high weld speed and penetration necessary for the efficient welding of thicker workpieces [3].

Many scientific researchers are focusing on the laser welding of homogeneous or heterogeneous alloy [4–7], or the relationship between various operating parameters and the weld joint quality of laser-single arc hybrid welding, which includes analyzing the influence of shielding gas, providing spectral image of the welding region, controlling the welding droplet transfer mode [8–16]. The research of laser-twin-arc hybrid welding process is not mature. Therefore, in order to further understand the hybrid welding process and improve the application of this welding method, it is of great important to investigate the coupling mechanism of laser and the arcs.

This article conducts an intensive study on coupling mechanism of laser and arc plasma of alternate burning based on synchronous information including electrical signal, spectral signal and high-speed photography. The variations of arc shape, droplet transfer, radiation intensity, temperature of hybrid plasma and welds microstructure with and without laser addition were studied as well.

2. Experimental procedure

2.1. Experimental setup

As shown in Fig. 1, the heat source was a Nd:YAG laser(JK2003SM) combined with double arcs. The two wires were supplied by a V350-pro digital welder in a parallel manner. The laser, with the wavelength of 1064 nm, was focused by a lens with a focal distance of 300 mm into a spot about 0.8 mm on the surface of the workpiece. The laser spot was on the midpoint of the two arcs. The output power of the laser beam can be adjusted between 100 and 2000 W according to different welding conditions. The welding was of bead-on-plate type. The angle of the welding torch and workpiece was kept 60°. Q235A steel plate with the thickness of 6 mm was employed as workpiece. H08Mn2Si was used as welding wire. Chemical compositions of Q235A and $H08Mn_2Si$ are shown in Tables 1 and 2, respectively. The torches were kept stationary and the workpiece moved with the moving stages. Therefore, bead welds were formed on the plates. Argon with a purity of 99.99% was utilized

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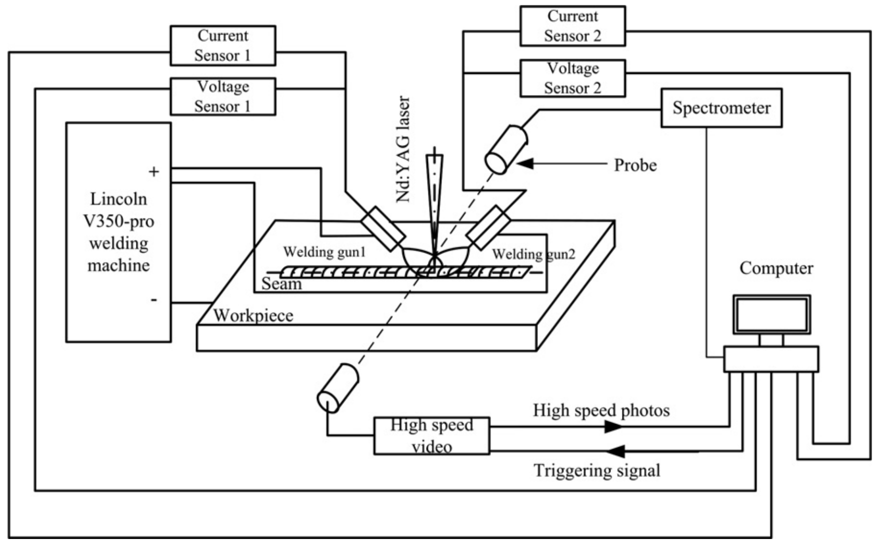

Fig. 1. Schematic of laser-twin-arc hybrid welding system.

Table 1
Chemical compositions [mass%] of Q235A (balance Fe).

C	Mn	Si	P	S
0.14–0.22	0.30–0.65	≤ 0.3	≤ 0.05	≤ 0.045

Table 2
Chemical compositions [mass%] of H08Mn2Si (balance Fe).

C	Mn	Si	P	S	Cr	Ni	Cu
≤ 0.11	1.80–2.10	0.65–0.95	≤ 0.025	≤ 0.015	≤ 0.20	≤ 0.30	≤ 0.50

Table 3
Welding parameters.

Welding speed	Wire feed rate	Laser power	Shielding gas
5 mm/s	2 m/min	500–1500 W	CO_2+Ar
Defocus distance	Gas flow rate	Average current	Average voltage
−2–2 mm	20 L/min	70–100 A	25–28 V

as the shielding gas and the flow rate is 20 L min^{-1}. Other parameters are provided in Table 3. In order to compare the radiation, the same parameters were employed in processes of twin-arc and laser-twin-arc hybrid welding.

HOTRON FASTCAM Super 10KC high-speed camera was adopted and positioned towards the laser spot position to record the image of the arc plasma. To characterize the welding plasma, a spectrograph (AvaSpec-2048) with resolution of 0.16 nm and a wavelength range from 200 nm to 820 nm was utilized. Two pairs of homemade current and voltage sensors were adopted to get the current and voltage values of both welding circuits in real-time, respectively.

2.2. Experimental method

The spectrograph was triggered by a given external pulsed trigger signal. Spectral signal was collected on each rising edge of pulse. Light emitted from the arc plasma is collected by a fiber head fixing on a bracket which can move vertically and horizontally. In this research, hollow probe method is adopted, i.e., a thin tube with 100 mm long and 1.0 mm diameter mounting towards the fiber head. Compared with the traditional slit image method, the hollow probe method has the advantage in providing the exact spatial location with X-axis and Y-axis information. Furthermore, only a small range of radiation about 1.0 mm in diameter is allowed to pass the probe and the radiation heat is cut down dramatically. This is important for resolving the problems of radiation saturation and spectrograph protection [17].

DAQ Card (Data Acquisition Card) accepted the signal transferred from the electrical sensors under the control of computer, and then realize the A/D conversion.

Electrical signal, high-speed camera signal and spectrographic signal were triggered by DAQ Card through homemade software to realize synchronization.

Fig. 2 shows the principle of the synchronization. Take one of the arcs as example. Fig. 2a is the time-varying current and voltage value. The current value of arc fluctuates between 50 A and 400 A (position 2) when burning; otherwise the current value is close to zero (position 1). Fig. 2b is an external trigger pulsed signal, when the rising edge corresponds to arc burning, spectral radiant intensity is strong, and arc is bright; when the rising edge corresponds to extinguished state, spectral radiant intensity is extremely weak, and arc is dark at that time.

To acquire the spatial radiation of the plasma, the hybrid plasma was divided into three layers with about 3.0 mm intervals along vertical direction. In every layer, four points with about 2.0 mm intervals on both sides of the laser point were selected, respectively. On each point, spectrum was collected continuously with a frequency of 4 Hz for 8 s. In order to get more accurate measurement, this collection repeated five times, and then the average value was taken as the radiation intensity of this point. Therefore, the spatial distribution of arc plasma in a period of time is acquired.

Six characteristic lines were selected to calculate the electron temperature of hybrid plasma using Boltzmann fitting method. In order to explore the influence of laser parameters on electron temperatures, electron temperatures of laser point were studied under the different laser powers and defocusing distances during the laser-twin-arc hybrid welding process. When the laser power was kept 1.5 kW, the defocusing distance changed from −2 mm to 2 mm, with 1 mm increment. While the defocusing distances was set to be 0 mm, the laser power changed from 0.5 kW to 1.5 kW by the increment of 0.2 kW.