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Characteristics of plasma plume and effect mechanism of lateral restraint during high power CO_2 laser welding process

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ABSTRACT

A novel lateral restraint method was proposed to suppress plasma plume of high power CO_2 laser welding using a pair of copper blocks with cooling water. The plasma plume was observed with a high-speed camera, and its core zone and periphery zone were investigated based on the specific processing algorithm. With the specially designed shifting unit, the spectrum of plasma plume was scanned both in 1-D and 2-D mode. Based on the selected spectral lines, electron temperature and electron number density of plasma plume were calculated. The characteristics of plasma plume, as well as the restraint mechanism, were discussed both in 1-D and 2-D mode. Results showed that the cooling effect, blowing effect and the static pressure were enhanced by the lateral restraint, and the restraint effect of the near-wall low-temperature area limited the expansion of plasma plume greatly.

1. Introduction

High power laser welding has been used widely in industries because of its high efficiency, narrow HAZ and low distortion. Especially, it has been a potential technology for high-thickness plate welding resulting from its great capability in penetration recently [1]. More metal vapor evaporated from material surface in high power laser welding leads to stronger interaction between laser and plasma plume [2,3]. The thinner plasma near the material surface will help energy transport from laser to work piece [4]. In fact, the dense plasma in the incident direction will shield or even block laser energy because of absorption, diffraction, and scattering [2,5,6]. It would be quite severe for high power CO_2 laser welding on account of its wavelength.

Much research work had been tried to suppress laser induced plasma during CO_2 laser welding process. As the most common method, assist gas was used to blow away the high-temperature metal vapor on the laser beam path. The parameters, such as gas flow rate, composition, nozzle structure and so on, were analyzed by many researchers numerically or experimentally [4–6]. Normally, helium gas was the best choice for CO_2 laser welding because of its high ionization energy and thermal conductivity, but its high price also brought heavy economic burden to industries. Recently, several new approaches were developed to suppress plasma plume besides assist gas. Tse et al. [7,8] studied the relationship between magnetic field intensity and weld penetration during high power CO_2 laser welding . However, there were many limitations in actual applications because of interference problems caused by magnetic field on surrounding equipment. Besides, the effect of groove on plasma plume attracted attention of some researchers. The plasma plume inside the deep and narrow groove shows difference comparing with on-plate [9]. Hamadou et al. [9] conducted high power laser welding with grooves of different shapes and sizes, and drew conclusion that U-shaped groove was helpful in increasing weld penetration. However, there was no further published paper on this point.

In this paper, a novel approach was proposed to suppress plasma plume during high power CO_2 laser welding. The spatial restraints were used unconventionally as effective supplementary units to suppress plasma plume and to maintain welding process stably. Experimental results showed that the method of lateral restraints was quite effective and convenient to suppress plasma plume, and to keep welding process stable. However, the influence mechanism of the method was not clear, which hindered the further development and promotion in industrial application. For this purpose, a special device was designed to detect 1-D and 2-D distributions of both electron temperature, electron number density and ionization degree, based on which the effect of lateral restraint on laser induced plasma was investigated by the additional assistance of high-speed camera.

2. Experimental procedure

Fig. 1 shows the schematic diagram of experimental setup. The artificial lateral restraint was established with a pair of copper blocks symmetrically laid near the incident point of laser along the

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welding direction. The size of water cooling copper block was 150 mm × 10 mm × 10 mm. Different from constant depth of the gap (10 mm), the gap width between the two blocks was adjusted from 2 mm to 8 mm with interval of 2 mm. Namely, the widths between the cooling blocks were 2 mm, 4 mm, 6 mm and 8 mm, respectively during experiments. It is important to note that the width was defined as ∞ mm when the on-plate welding was conducted without any restraints.

The power of the continuous wave CO_2 laser is 7000 W, and the diameter of the laser focal spot was 0.8 mm. The travelling speed was 1 m/min for all welding processes. The diameter and inclination angle of gas nozzle were 4 mm and 45°, respectively. The distance between the nozzle end and the top surface of work piece was 14 mm. Helium with flow rate of 20 L/min was used as shield gas. The welding material used in this study was low carbon steel mainly containing iron.

During the laser welding process, a high resolution spectrograph, HR4000, was controlled by a remote trigger to collect spectral lines of laser induced plasma plume above the work piece. The detection range of the HR4000 high solution spectrometer was from 500 to 600 nm. The resolution of HR4000 was 0.1 nm and minimum integral time was 3.8 ms. The image of plasma plume was amplified and projected on a screen through an optical system consisting of a set of lens and a diaphragm. The optical fiber head was positioned on the center of the screen. The diameter of the fiber is 0.22 mm. The *f* denoted the focal length of the lens and *f* equals to 20 cm. Image of the plasma plume on the screen was amplified twice. The optical fiber head

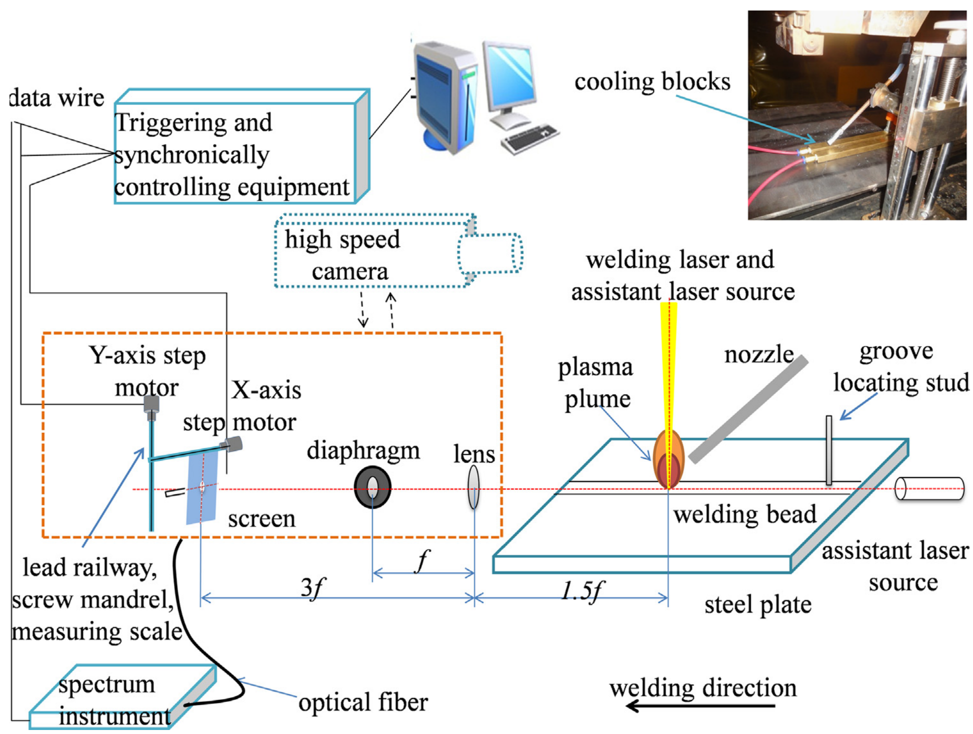

Fig. 1. Construction of experimental platform.

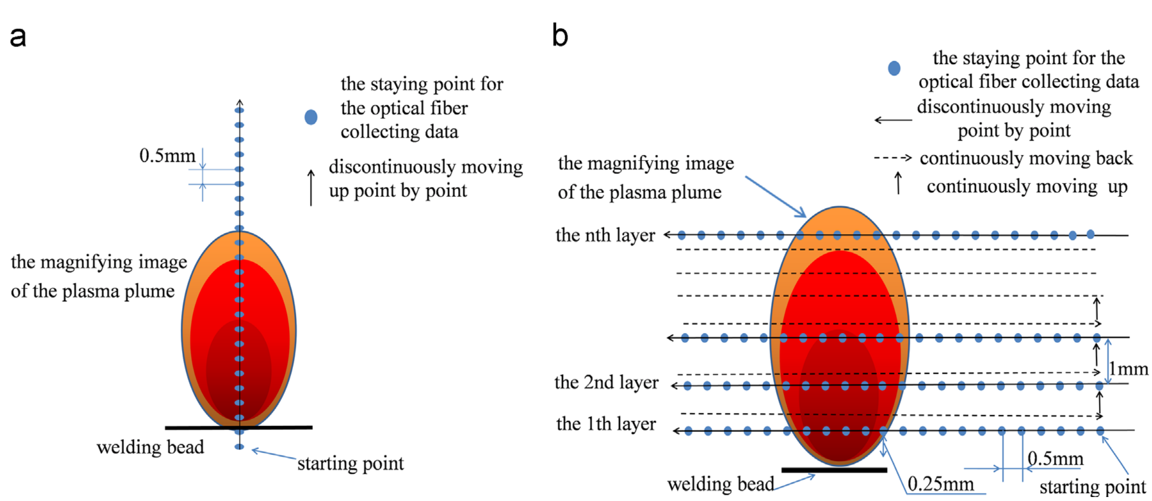

Fig. 2. Scanning ways of the mechanical unit with the scanning tracks. The arrow lines are the trace of screen with the optical fiber head: (a) 1-D scanning mode along the Y-direction of laser incident and (b) 2-D scanning mode layer by layer along X-direction.