Influence of shielding gas pressure on welding characteristics in CO_2 laser-MIG hybrid welding process

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The droplet transfer behavior and weld characteristics have been investigated under different pressures of shielding gas in CO_2 laser and metal inert/active gas (laser-MIG) hybrid welding process. The experimental results indicate that the inherent droplet transfer frequency and stable welding range of conventional MIG arc are changed due to the interaction between CO_2 laser beam and MIG arc in laser-MIG hybrid welding process, and the shielding gas pressure has a crucial effect on welding characteristics. When the pressure of shielding gas is low in comparison with MIG welding, the frequency of droplet transfer decreases, and the droplet transfer becomes unstable in laser-MIG hybrid welding. So the penetration depth decreases, which shows the characteristic of unstable hybrid welding. However, when the pressure of shielding gas increases to a critical value, the hybrid welding characteristic is changed from unstable hybrid welding to stable hybrid welding, and the frequency of droplet transfer and the penetration depth increase significantly.

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Recently, laser and metal inert/active gas (laser-MIG) hybrid welding technology has increasingly attracted interest in both industry and academia[1]. But most of these researches in this area were experimental, and the effects of various welding parameters, including laser power, arc current, welding speed, and distance from the beam axis to the electrode on weld penetration, were investigated[2−5]. However, the effect of shielding gas pressure on weld penetration and physical phenomena of droplet transfer in the hybrid welding has not been reported. In this paper, the experimental results show that the shielding gas pressure also has an important effect on the frequency of droplet transfer and the welding stability in CO_2 laser-MIG hybrid welding process.

The experimental setup of laser-MIG hybrid welding is shown in Fig. 1. The welding system is constituted of a diffusion cooling CO_2 laser with the maximum power of 3.0 kW and a DC-MIG welding machine with 500-A current rating. The electrode wire used for MIG process is ER5356 of 1.2 mm in diameter. A high-speed camera, 1000 frames per second, is positioned to record the transfer of droplet. All experiments are performed on LF6 aluminum alloy of 5.0 mm in thickness with bead-on-plate welding mode. The distance D_{LA} and the angle α between laser beam and electrode wire are shown in Fig. 1. Industrially pure argon is delivered to the workpiece surface through the nozzle of welding torch.

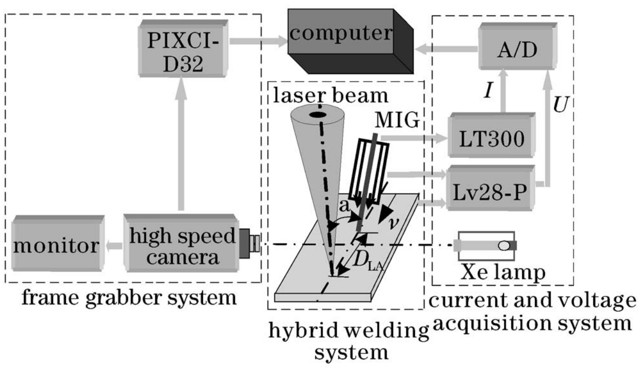

Fig. 1. Schematic of laser-MIG hybrid welding experimental system.

Compared with the pure MIG welding, the inherent droplet transfer frequency of conventional MIG arc is changed due to the interaction between CO_2 laser beam and MIG arc in laser-MIG hybrid welding process[6,7]. Figure 2 shows the relationship between the increment rate of frequency of droplet transfer and the shielding gas pressure in the CO_2 laser-MIG hybrid welding with projected mode. And the increment rate of frequency of droplet transfer R_f can be calculated by

$$R_f = \frac{f_H - f_M}{f_M} \times 100\%, \tag{1}$$

where f_H is frequency of droplet transfer in hybrid welding, f_M is frequency of droplet transfer in MIG welding.

When the increment rate of frequency R_f is negative, it is indicated that the average frequency of droplet transfer decreases in the hybrid welding compared with that in the MIG welding. On the contrary, the average frequency of droplet transfer increases. In order to

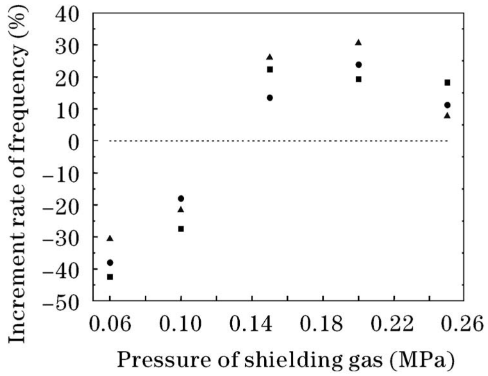

Fig. 2. Relationship between the increment rate of droplet transfer frequency and shielding gas pressure. P = 1200 W, I = 150 A, V = 1.0 m/min, D_{LA} = 2.0 mm, $\alpha = 40°$.

Fig. 3. Droplet detachment of the pure MIG welding. $I =$ 150 A.

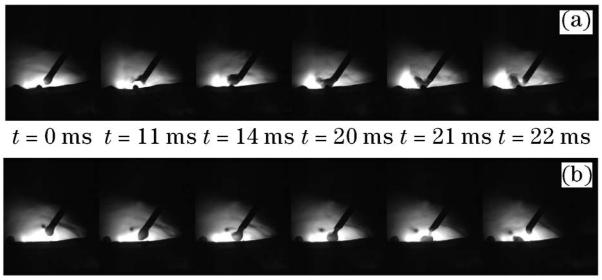

Fig. 4. Droplet detachment of the hybrid welding with projected mode at different shielding gas pressures of 0.10 (a) and 0.15 MPa (b). $P = 1200$ W, $I = 150$ A, $D_{\mathrm{LA}} = 2.0$ mm.

ensure the validity, the experiment is carried out for 3 times with the same parameters.

Compared with the pure MIG welding shown in Fig. 3, due to the attraction of laser plasma to arc and the jet force of metal vapor to droplet, the droplet deflects toward laser beam during the droplet growing up and detaching at a lower pressure of shielding gas. As a result, the growing period of droplet becomes long, the dimension of droplet becomes large, which results in the decrease of the frequency of droplet transfer and the instability of droplet transfer, as shown in Fig. 4(a). At this time, the hybrid welding exhibits a shallow penetration and shows the characteristic of unstable hybrid welding process. With the augment of shielding gas pressure, the frequency of droplet transfer increases gradually. When the pressure of shielding gas R_{g} is increased to 0.15 MPa, the frequency of droplet transfer is the highest. At the same time, the dimension of droplet becomes small, and the transfer stability is enhanced as shown in Fig. 4(b). As a result, the penetration depth is increased and a sound weld appearance is obtained, which creates the characteristic of stable hybrid welding process (see Fig. 5). The reason is probably that the shielding gas suppresses effectively the growth of laser plasma and metal vapor. All these above show that the hybrid welding characteristic can also be changed from unstable hybrid welding into stable hybrid welding by altering the pressure range of shielding gas.

For the CO_2 laser-MIG hybrid welding with short-circuiting mode, the characteristics of droplet transfer

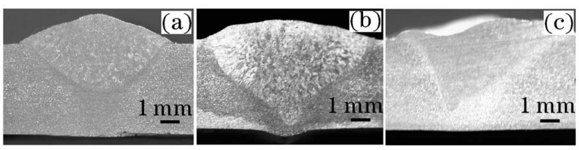

Fig. 5. Bead cross-sections of hybrid welding at different shielding gas pressures of 0.06 (a), 0.15 (b), and 0.25 MPa (c). $P = 1200$ W, $I = 150$ A, $D_{\mathrm{LA}} = 2.0$ mm.

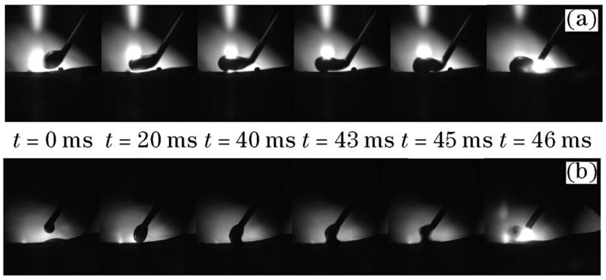

Fig. 6. Droplet detachment of the hybrid welding with short-circuiting mode at different shielding gas pressures of 0.06 (a) and 0.25 MPa (b). $P = 1700$ W, $I = 100$ A, $D_{\mathrm{LA}} = 2.0$ mm.

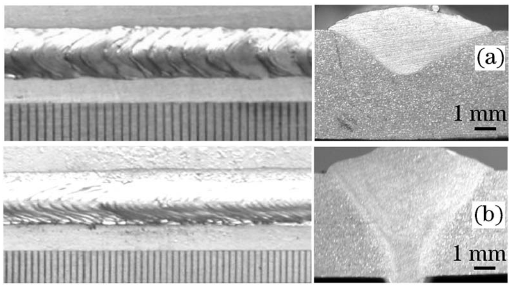

Fig. 7. Weld appearance and cross-section of hybrid welding at different shielding gas pressures of 0.06 (a) and 0.25 MPa (b). $P = 1700$ W, $I = 100$ A, $D_{\mathrm{LA}} = 2.0$ mm.

and the variation laws of weld penetration are consistent with those of hybrid welding in projected mode. But the effect of shielding gas pressure on welding characteristics becomes more evident. Figures 6 and 7 show the droplet transfer and bead cross-section respectively at different pressures of shielding gas. When the pressure of shielding gas is low, the weld ripple becomes sparse and discontinuous, and some defects occur at the surface, as shown in Fig. 7(a). When the pressure of shielding gas increases to some extent, the unstable hybrid welding is transformed into the stable hybrid welding again. The droplet transfer becomes uniform and stable. And weld appearance is greatly improved, a typical Y-shape penetration weld is also obtained, as shown in Fig. 7(b).

In addition, it has been observed from these experiments, whether projected mode or short-circuiting mode, the plasma and the metal vapor caused by laser-induced keyhole mainly affect the droplet transfer and the welding stability in laser-MIG hybrid welding process. There are remarkable diversities in producing laser plasma and metal vapor with varying laser power. As a consequence, in order to obtain a stable hybrid welding, the optimum pressure range of shielding gas is distinct, too. With the increase of the laser power, the optimum pressure range resulting in the stable hybrid welding should also be enhanced correspondingly. In other words, there is an optimum matching range between laser power and shielding gas pressure in CO_2 laser-MIG hybrid welding process, as shown in Fig. 8.

In conclusion, the plasma and metal vapor caused by laser have a greater effect on the droplet transfer and the welding stability in CO_2 laser-MIG hybrid welding

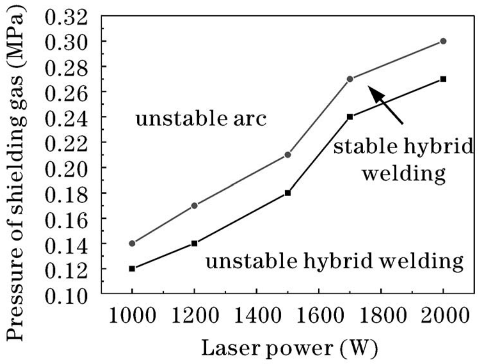

Fig. 8. Relationship between laser power and shielding gas pressure in a stable hybrid welding process. $V = 1.0$ m/min, $D_{\mathrm{LA}} = 2.0$ mm, $\alpha = 40^\circ$.

process. And choosing a proper pressure range of shielding gas can suppress effectively laser plasma and metal vapor, and obtain the characteristic of the stable hybrid welding process.

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References

1. D. Petring, C. Fuhrmann, N. Wolf, and R. Poprawe, in *Proceedings of the 22nd International Congress on Applications of Lasers & Electro-Optics* 1 (2003).
2. E. Schubert, B. Wedel, and G. Kohler, in *Proceedings of the 21st International Congress on Applications of Lasers & Electro-Optics* (2002).
3. M. Ono, Y. Shinbo, A. Yoshitake, and M. Ohmura, NKK Tech. Rev. **86,** 8 (2002).
4. D. Travis, G. Dearden, K. G. Watkins, E. W. Reutzel, R. P. Martukanitz, and J. F. Tressler, in *Proceedings of the 23rd International Congress on Applications of Lasers & Electro-Optics* (2004).
5. X. Zhang, W. Chen, Y. Shuang, and K. Wang, Appl. Laser (in Chinese) **25,** 1 (2005).
6. Z. Lei, Y. Chen, L. Li, and L. Wu, Appl. Laser (in Chinese) **24,** 361 (2004).
7. K.-D. Lee and K.-Y. Park, in *Proceedings of the 22nd International Congress on Applications of Lasers & Electro-Optics* 48 (2003).