The Influence of Laser Power and Butt Gap on the Droplet Transfer and Weld Formation of Laser Arc Hybrid Welding

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Abstract. In this study, an 8mm thick AH36 steel plate was welded using laser + MAG hybrid welding technology. The results show that when the laser power is low, the droplet transition form is droplet transition, the droplet size is larger, and the transition frequency is low. As the laser power increases, the form of droplet transition is jet transition, the droplet size is small, and the transition frequency is high. When the laser power is low, the undercut phenomenon of the weld is serious. With the increase of the laser power, the undercut phenomenon of the weld is improved. Besides, the weld width and welding seam reinforcement will also increase. Laser-arc hybrid welding has a certain gap adaptability. When the laser power is 10KW, the weld profile of 0mm welding gap and 1mm welding gap are basically the same. Properly reducing the laser power is conducive to the larger welding assembly gap of laser arc hybrid welding.

1. Introduction

As a new type of welding technology, laser-arc hybrid welding fully integrates the advantages of laser welding and arc welding. It combines laser beam with arc to work. These two heat sources influence each other [1–3]. It has high process stability and bridging, large gap and wide material adaptability. The laser beam and the arc work together under the premise of ensuring the penetration depth, so that the heat input is rapidly reduced in the thickness direction. The molten pool of laser-arc hybrid welding is smaller than that of arc welding, the heat input is low, the heat-affected zone is small, and the deformation of the workpiece is small, which greatly reduces the work of correcting welding deformation after welding. The heat source of the laser has the function of guiding the molten filler metal to the bottom of the weld, so that the weld of the hybrid welding is smooth, the stress concentration factor is reduced, and the fatigue strength is high. Therefore, it is great significant to study the influence of laser power and butt gap on the molten pool flow and weld formation in laser arc hybrid welding.

This experiment mainly uses laser arc hybrid welding to weld AH36 steel plate. Compare the change rule of droplet transfer and weld formation in the welding process of AH36 steel plate under different process parameters, and study the influence of laser power and butt gap on droplet transfer...
and weld formation. The results of this experiment can provide theoretical support for follow-up research.

2. Experiment

2.1. Materials

In this experiment, AH36 steel plate is used as the welding model, the size of the butt joint test plate is 300×150×8mm. This experiment use JM-56 welding wire, and the diameter of the welding wire is 1.2mm. The chemical composition of base metal and welding wire are shown in table 1.

| C  | Si  | Mn  | Mo  | Cr  | V   | P   | S   | Cu  | Ni  | Nb  | Ti  | Al  |
|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| AH36 | 0.157 | 0.392 | 1.501 | -   | 0.030 | 0.003 | 0.014 | 0.003 | 0.015 | 0.010 | 0.002 | 0.003 | 0.042 |
| JM-56 | 0.077 | 0.87 | 1.45 | 0.002 | 0.031 | 0.004 | 0.012 | 0.013 | 0.125 | 0.017 | -   | -   | -   |

The laser used in this experiment is TruDisk16002 equipment. The hybrid welding equipment and high-speed camera equipment are shown in figure 1. The shielding gas is used in the hybrid welding process is a mixed gas composed of 80% Ar and 20% CO₂, and the shielding gas flow rate is 20L/min during welding. High-speed camera works at 1000 frames per second. The detailed welding parameters are shown in table 2.

| Board thickness (mm) | Laser power (KW) | Arc voltage (A) | Arc current (V) | Welding speed (mm/s) | Defocus (mm) | Assembly clearance (mm) |
|---------------------|------------------|-----------------|-----------------|----------------------|-------------|------------------------|
| 8                   | 9                | 248             | 29              | 39                   | 0           | 0                      |
|                     | 9                | 248             | 29              | 39                   | 0           | 1                      |
|                     | 10               | 248             | 29              | 39                   | 0           | 0                      |
|                     | 10               | 248             | 29              | 39                   | 0           | 1                      |
|                     | 11               | 248             | 29              | 39                   | 0           | 0                      |
|                     | 11               | 248             | 29              | 39                   | 0           | 1                      |

Figure 1. Laser-MAG arc composite welding device and high-speed camera device

2.2. Experimental Method

This experiment uses laser + MAG hybrid welding method to weld 8mmAH36 steel plate. During the welding process, the laser is at the front and the arc is at the back. During the welding process, a high-
speed camera experiment was carried out simultaneously to analyse the change of the droplet transition form under different laser powers.

Three welds per laser power or welding gap. Measure the width and seam reinforcement of the weld on the front and back of the weld. Measure the front, middle and back three points and take the average value. Study the influence of different laser power and butt gap on the width and seam reinforcement of the weld.

Use 4% sulfuric acid alcohol to corrode, and then use a stereo microscope to photograph the cross-sectional profile of the weld. Compare the changes of weld profile under different laser power and butt gap.

3. Results and Discussion

The pros and cons of the droplet transfer are very important to the welding quality [4]. In the process of welding, the end of the welding wire is heated and continuously melted to form a droplet. The droplet gradually grows and separates from the end of the wire, then its transitions into the molten pool. The droplet transfer forms are generally divided into short-circuit transfer, droplet transfer, and spray transfer. As shown in figure 2(a), when the laser power is 9KW, the droplet transition is in the form of droplet transition, and the droplet size is larger. As shown in figure 2(b), when the laser power is 10KW, comparing with the time of 9KW, the droplet size is reduced, the transition frequency is increased, and the transition is still droplet. As shown in figure 2(c), when the laser power is 11KW, the droplet transition is in the form of jet transition. The droplet size is smaller and the transition frequency increases. This is because when the laser power is low, the thermal radiation effect of the laser photo plasma on the droplet is small, and the thermal radiation effect of the laser photo plasma on the droplet can effectively reduce the surface tension coefficient of the droplet, so as to reduce the surface tension of the droplet. The laser power is small, the heat radiation effect on the droplet is small, and it cannot effectively promote the refinement of the droplet. thus forming a larger droplet transition with a small droplet transition frequency. As the laser power increases, the laser energy density increases, and the thermal radiation effect of the laser photo plasma on the droplet increases, and the surface tension of the droplet decreases, making it easier to refine and form a jet transition.

Figure 2. (a) The droplet transition when the laser power is 9KW; (b) The droplet transition when the laser power is 10KW; (c) The droplet transition when the laser power is 11KW.

As shown in figure 3, the weld shape of laser-MAG hybrid welding is a typical "nail" shape. The weld profile is good and the arc zone is small. The laser area is narrow and the pen reaches the bottom with good penetrating effect. This is because in the laser-MAG hybrid welding process, the arc
welding first melts the metal surface, which greatly reduces the reflectivity of the workpiece surface, and at the same time, the plasma area of the arc and the molten welding wire have a certain absorption effect on the laser, which makes the laser energy transmission more stable. As shown in figure 3(a), when the laser power is 9KW, the undercut phenomenon of the weld is serious. This is because when the laser power is low during the welding process, the arc absorbs more laser energy, which makes the energy acting on the surface of the metal larger. However, part of the laser energy is absorbed by the arc, resulting in a decrease in the energy acting on the inner metal layer. The accumulation of a large amount of energy on the surface of the metal causes the metal in the molten pool to flow quickly to the inner layer. The inner laser area has less energy, the molten pool flows slowly, and there is less surface metal filling upwards, resulting in undercutting after solidification. At the same time, the droplet-shaped transition form with larger size and smaller frequency will cause uneven distribution of the molten droplets in the molten pool, which may easily cause splashing. As shown in figure 3(b), when the laser power is 10KW, the weld undercut is smaller than when the laser power is 9KW. As shown in figure 3(c), when the laser power is 11KW, there is no undercut in the weld. The spray transition form with small size and high frequency makes the droplets evenly enter the molten pool, and the welding wire is evenly distributed in the weld. As the laser power increases, the laser energy acting on the inner metal layer increases, and the undercut phenomenon of the weld is improved. As shown in figure 3(b) and 3(d), when the laser power is 10KW, the weld profile of the 0mm welding gap and the 1mm welding gap are basically the same. The molten pool formed by laser-MAG hybrid welding is larger, which is better than pure laser welding or arc welding, and allows a larger welding assembly gap.

![Figure 3. Weld contour comparison (a) Weld contour under 9KW, 0mm welding gap; (b) Weld contour under 10KW, 0mm welding gap; (c) Weld contour under 11KW, 0mm welding gap; (d) 10KW, weld contour under 1mm welding gap.](image)
During this experiment, other welding parameters are unchanged, but the laser power and butt gap are changed. The laser power is 9KW, 10KW, 11KW, and the welding gap is 0mm and 1mm. As shown in figure 4(a), when the laser power is increased from 9KW to 11KW, the front welding width of the 0mm welding gap first increases and then decreases, but the front welding width of the 1mm welding gap first decreases and then increases. When the laser power is 9KW and 11KW, the welding seam width of 1mm welding gap is larger than that of 0mm welding gap. When the laser power is 10KW, the 1mm welding gap is smaller than the welding seam front width of 0mm welding gap. As shown in figure 4(b), the width of the back side of the weld increases with the increase of the laser power at the 0mm welding gap and 1mm welding gap. The width of the back side of the weld is formed by the action of laser energy. As the laser power increases, the laser energy absorbed by the welding material increases, the molten pool in the laser area increases, and the width of the weld increases. Under the same power, when the butt gap is 0mm and 1mm, the width of the back side of the welding seam is similar and the 1mm welding gap is larger than that of the 0mm welding gap.

![Figure 4](image-url)

**Figure 4.** (a) Weld width of front side; (b) Weld width of back side; (c) welding seam reinforcement of front side; (d) welding seam reinforcement of back side.

As shown in figure 4(c), with the increase of laser power, the welding seam reinforcement of front side with 0mm welding gap gradually increases. When the laser power is increased from 9KW to 10KW, there is little change in the welding seam reinforcement of front side of the 1mm welding gap. As shown in figure 4(d), with the increase of laser power, the welding seam reinforcement of back side of 0mm welding gap and 1mm welding gap gradually increases. As the laser energy increases, the energy density of the laser area increases, and the welding seam reinforcement of back side increases. Compared with the 0mm welding gap, the welding seam reinforcement of the 1mm welding gap is larger than that of the 0mm welding gap on the back side of the welding seam increases faster. At the same power, the welding seam
reinforcement of 1mm welding gap is bigger than the welding seam reinforcement of 0mm welding gap on the back side. As shown in figure 4(c) and 4(d), when the laser power is 9KW, the welding seam reinforcement of 0mm and 1mm welding gap is similar. With the increase of laser power, the difference between the welding seam reinforcement of 0mm and 1mm welding gap becomes larger. Properly reducing the laser power is conducive to the larger welding assembly gap of laser arc hybrid welding.

4. Conclusions
In this paper, the laser + MAG hybrid welding method is used to study the droplet transfer form, the cross-sectional profile of the weld, the width of the weld and the height of the weld under different process. The main conclusions are as follows:

(1) When the laser power is 9KW to 10KW, the droplet transition is in the form of droplet transition, the droplet size is large and the transition frequency is low. When the laser power is 11KW, the droplet transition form is jet transition, the droplet size is small, and the transition frequency is high.

(2) As the laser power increases from 9KW to 11KW, the undercut phenomenon of welds can be improved. When the laser power is 9KW, the undercut phenomenon of the weld is serious.

(3) When the laser power is 10KW, the weld profile of 0mm butt gap and 1mm butt gap are basically the same.

(4) The weld width and reinforcement of the back side increases with the increase of laser power. At the same power, the welding seam reinforcement of 1mm welding gap is bigger than the welding seam reinforcement of 0mm welding gap on the back side.

(5) When the laser power is 9KW, the weld heights of 0mm and 1mm welding gaps are similar. Properly reducing the laser power is conducive to the larger welding assembly gap of laser arc hybrid welding.

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