Research on Laser DP-TIG Hybrid Thin Plate High-Speed Welding Process

Jialei Zhu, Cong Feng, Xiangdong Jiao, Zhibo Li, and Wei Li

Abstract Deep penetration TIG welding (DP-TIG) is a new efficient automatic welding method. Compared with traditional TIG welding, it can effectively increase welding penetration and improve welding efficiency. In thin plate welding, laser DP-TIG hybrid welding can significantly improve the welding speed on the premise of ensuring good weld formation. Taking the Q345B steel plate of 2 and 4 mm thickness as the base material, on the premise of ensuring the welding quality, this paper explores the maximum welding speed that can be achieved by laser DP-TIG hybrid welding under the conditions of hydrogenation of shielding gas, filler wire and different gaps and misalignment. The results show that the laser DP-TIG hybrid welding can significantly improve the welding speed and has good adaptability to the gap and misalignment. Adding a certain amount of hydrogen and filler wire in the experiment is beneficial to improve the weld formation and welding speed.

Keywords DP-TIG · Hybrid welding · High-speed welding

1 Introduction

Laser welding, as a kind of high energy beam welding, has the advantages of high welding speed, deep penetration, high degree of automation and small deformation. However, the welding method requires high assembly accuracy of workpiece [1–3]. In order to solve the problems of high cost and poor bridging of laser welding, W. M. Steen, a British scholar, first proposed the concept of laser arc hybrid welding in the

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Table 1 Chemical composition of Q345B mild steel and fill wire (wt%)

Category	C	Si	Mn	P	S	V	Cr	Ni	Cu	Ti
Q345B	0.09	0.35	1.65	0.03	0.03	0.15	0.2	0.45	0.28	0.1
JM-68	0.09	0.77	1.61	0.01	0.01	0.004	0.06	0.06	0.025	–

early 1980s [4]. He combined two kinds of heat sources with completely different physical properties and energy transfer mechanisms, which not only gave full play to their advantages, but also made up for their disadvantages [5, 6].

The DP-TIG welding method realizes arc compression, improves energy density and increases welding penetration through high-speed cooling of tungsten electrode. Compared with TIG welding, this method has higher arc stiffness and higher energy density, which can realize the welding in the form of perforation and obtain a more stable single-sided welding and double-sided forming welding process [7].

In this paper, the laser DP-TIG hybrid method was used for welding experiments on 2 and 4 mm Q345B low carbon steel plates. By optimizing the welding parameters, the maximum welding speed of this method can be tested on the premise of good weld formation and no ultrasonic flaw detection defects. The arc shape and microstructure of the weld metal under the hybrid welding condition were studied as well. This is of great significance for the further study of this welding method and its application in industrial production.

2 Experimental Method

2.1 Experimental Materials

The test plate is Q345B low-alloy high-strength steel, with dimensions of 400 mm × 70 mm × 2 mm and 400 mm × 70 mm × 4 mm. The filler wire is jm-68 welding wire of Lincoln Jintai company, with a diameter of 1.2 mm. The chemical composition of test plate and filler wire are shown in Table 1.

2.2 Experimental Condition

The YLS-4000 fiber laser of IPG company was used in the experiment. The maximum laser power was 4 KW, and the focal length was 300 mm. It was mainly composed of laser welding head, control system, laser and water-cooling system. The DP-TIG welding machine is a Panasonic YC-500WX welding machine with a rated current of 500 A. It was connected to an external air feeding device and wire feeding device for integrated control. Using the DP-TIG welding torch independently developed by Tangshan Kaiyuan Group, the laser welding head and welding torch can adjust the

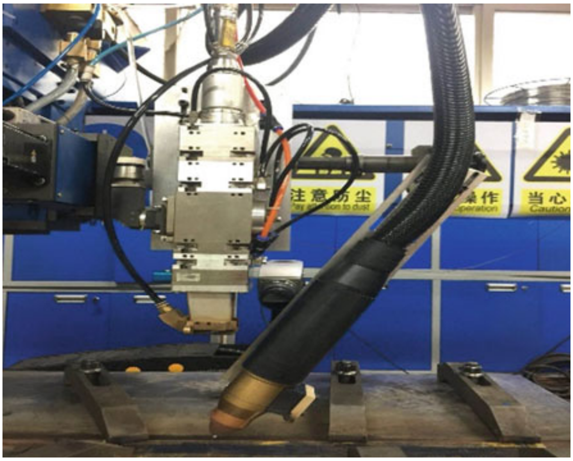


Fig. 1 Laser DP-TIG hybrid welding system

position and angle through the self-designed clamping device, as shown in Fig. 1. The multi-function CNC motion welding platform designed by Tangshan Kaiyuan Group can realize multi-axis composite motion, which can meet the various needs of laser arc hybrid welding, with convenient operation and high running accuracy.

Adopt the welding method of plate self-fusion welding and plate butt welding. Before welding, remove the oxide film on the surface of the workpiece and clean it with acetone to remove oil. Two composite welding processes are adopted: hydrogenation and non-hydrogenation. The former is a mixed gas of 95% argon and 5% hydrogen, while the latter is pure argon with a flow rate of 15 L/min. During the experiment, the defocus amount and the distance between the heat sources were both 0 mm. The forward wire feeding method and welding direction with laser in front and arc in back were used.

3 Experimental Results and Discussion

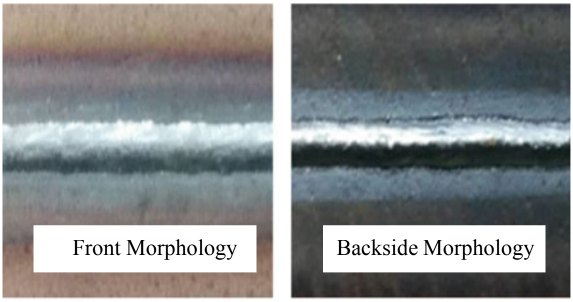
3.1 Research on 2 mm Test Plate Process

3.1.1 Pure Argon Shielding Gas

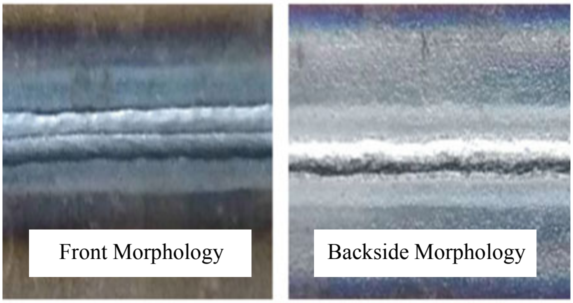
By adjusting the laser power and welding current, the plate self-fusion welding and plate butt welding were carried out. On the premise of ensuring the welding quality, the welding speed was gradually increased. In order to improve the quality of weld formation, a front wire feeding device was used in several groups of experiments to fill the wire. Several typical experimental results are shown in Fig. 2.

It can be seen from the experimental results that in the process of plate self-fusion welding, by adjusting the laser power and welding current, the welding speed can

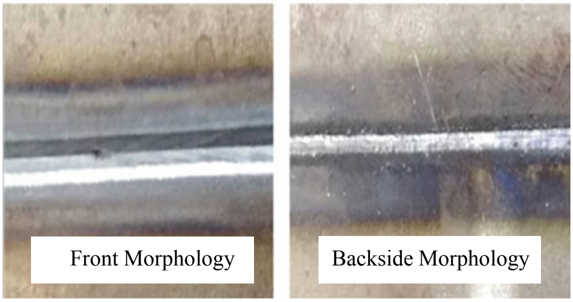
Fig. 2 Weld morphology of 2 mm thick and low carbon steel plate



(a) Plate self-fusion welding, P=2500W I=200A V=2.5m/min, Forward wire feeding



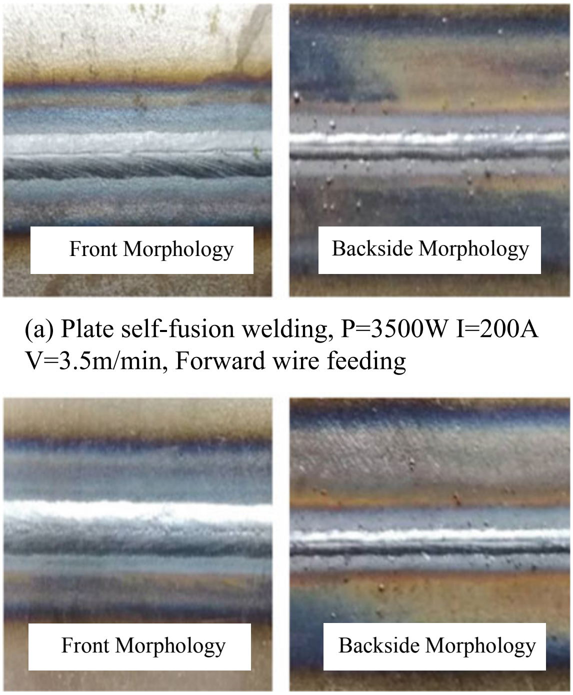
(b) Plate self-fusion welding, P=2500W I=200A V=3m/min, No wire feeding



(c) Plate butt welding, P=2500W I=150A V=2.5m/min, Forward wire feeding

reach 3 m/min on the premise of ensuring good weld formation while the speed of plate butt welding can reach 2.5 m/min. The addition of welding wire can improve the weld surface formation, but has no obvious effect on increasing the penetration and welding speed.

Fig. 3 Weld morphology of 2 mm thick and low carbon steel plate under hydrogen



(a) Plate self-fusion welding, P=3500W I=200A V=3.5m/min, Forward wire feeding

(b) Plate self-fusion welding, P=3500W I=200A V=4m/min, Forward wire feeding

3.1.2 Shielding Gas of 95% Argon and 5% Hydrogen Mixed Gas

Pass 5% active gas hydrogen gas into the protective gas and adjust the welding parameters to carry out the experiment. On the premise of ensuring good weld formation, the welding speed was gradually increased. Several groups of typical experimental results are shown in Fig. 3.

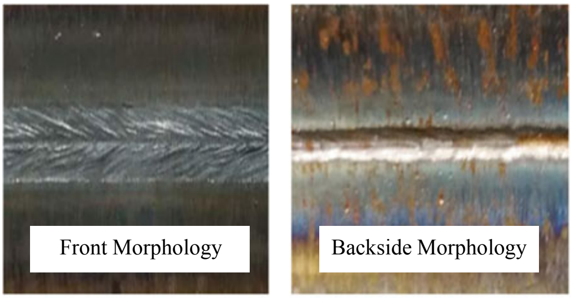
From the experimental process and results, it can be seen that in the process of plate self-fusion welding, passing a certain amount of hydrogen gas into the shielding gas can improve the melt pool fluidity and the weld formation. Moreover, the welding speed can be increased to 4 m/min. However, in the process of plate butt welding, shielding gas has little effect on welding speed.

3.2 Research on 4 mm Test Plate Process

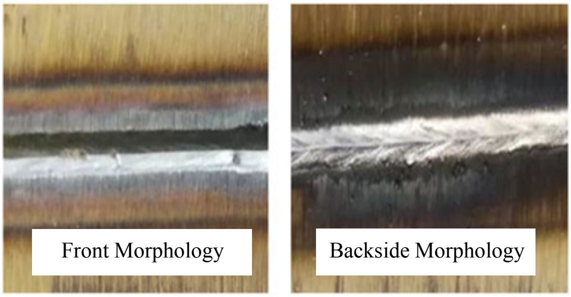
Taking 4 mm thick low carbon steel plate as the object, using hydrogen gas mixture as the shielding gas, using the wire filling method of front wire feeding, through adjusting the welding parameters, the experiments of plate self-fusion welding and plate butt welding were carried out. On the premise of good weld formation, the welding speed was gradually increased. Several typical experimental results are shown in Fig. 4.

It can be seen from the experimental results that the welding speed can be up to 2 m/min for plate self-fusion welding and 1.5 m/min for plate butt welding. The

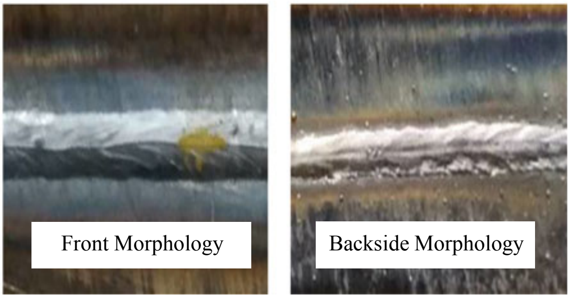
Fig. 4 Weld morphology of 4 mm thick and low carbon steel plate



(a) Plate butt welding, P=4000W I=150A V=1.5m/min, Forward wire feeding



(b) Plate butt welding, P=4000W I=150A V=1.5m/mim,0.5mm gap 1mm misalignment Forward wire feeding



(c) Plate self-fusion welding, P=4000W I=150A V=2m/min, Forward wire feeding welding process has good adaptability to gap and misalignment. The value of gap depends on the laser spot diameter. The maximum value is 0.5 mm, and the single misalignment can reach 1 mm.

3.3 Arc Shape Observation

In laser DP-TIG hybrid thin plate high-speed welding, the laser power decides the penetration, and the welding current plays the role of improving the weld formation and increasing the weld width. Therefore, on the premise of ensuring laser penetration, the welding current plays a major role in improving the welding speed. Several experiments under the condition of 2 mm plate thickness were filmed with high-speed camera to observe the influence of welding parameters on arc shape.

It can be seen from Fig. 5 that the laser has an attracting effect on the arc, and the hybrid arc is offset to the direction of the laser beam. The arc burns most intensely at the focus of the laser. In high-speed welding, this kind of attractive effect can better control the direction of the arc and improve the weld formation. In the process of hybrid welding, the welding current and laser power have an optimal matching parameter. From Fig. 4c and d, it can be seen that when the welding power is 2500 W and the welding current is 200 A, the arc stiffness and directivity are the best, and the effect of improving the weld formation and welding speed is the best. It can be seen from the Fig. 4d that when the current is too large, although the laser attraction to the arc still exists, the arc diverges at this time and the stability is poor. In addition, too much plasma produced by high current dilutes the laser energy, reduces the penetration, and the back cannot be formed when the welding speed is too fast.

3.4 Weld Microstructure

The metallographic specimen was prepared by selecting the welding specimen at the welding speed of 1.5 m/min, and the microstructure of the welded joint was observed by metallographic microscope. Figure 5 shows the microstructure of the hybird welded joint. The base material in Fig. 6a is mainly composed of pearlite and ferrite. The pearlite grains are located between the ferrite grains, and the grains are small; in Fig. 6b, the heat-affected zone consists of coarse-grained zone and fine-grained zone, which are mainly composed of martensite and bainite. Coarse-grained zone has high phase transition temperature, fast cooling speed and high hardness. The cooling speed of fine-grained zone is slower than that of coarse-grained zone which results in grain refinement. Therefore, the comprehensive performance of fine-grained zone is better than that of coarse-grained zone; Fig. 6c shows the central area of the hybrid weld, in which the white phase is the eutectoid acicular ferrite. The eutectoid ferrite grows in the form of columnar crystals, which is perpendicular to the fusion line and points to the midline of the weld. The rest of the structure is

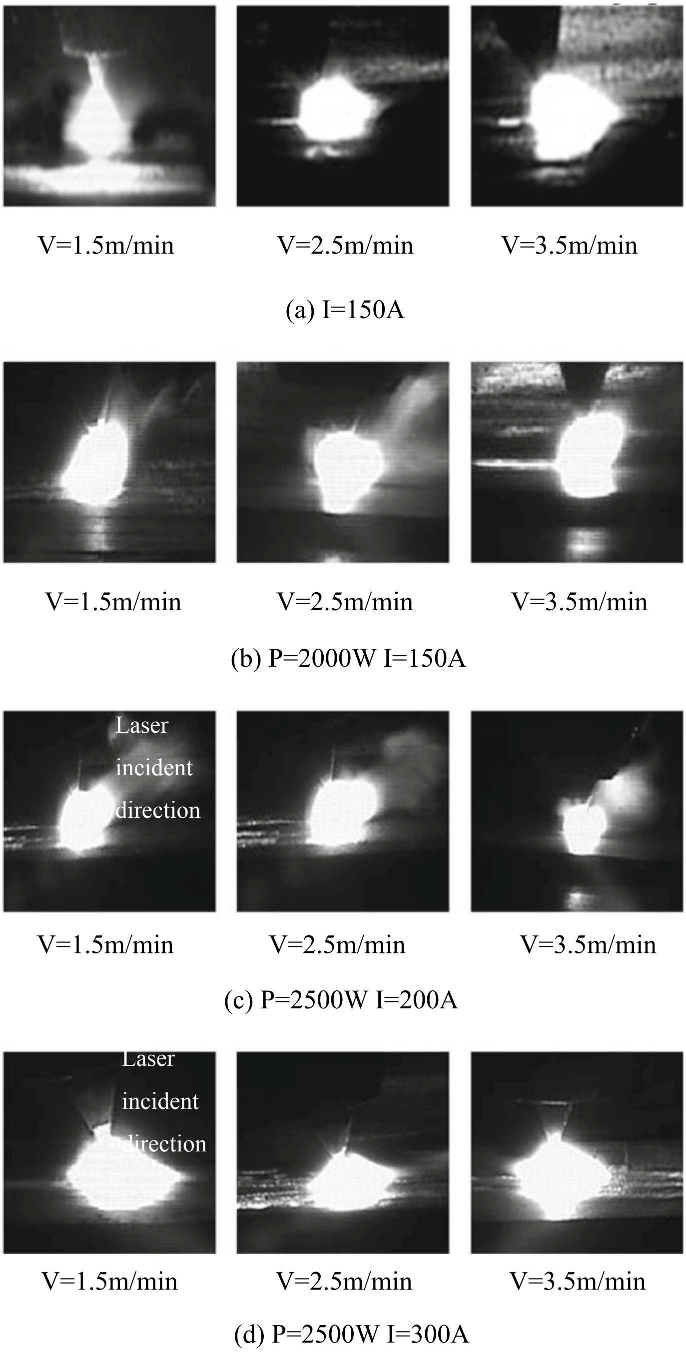
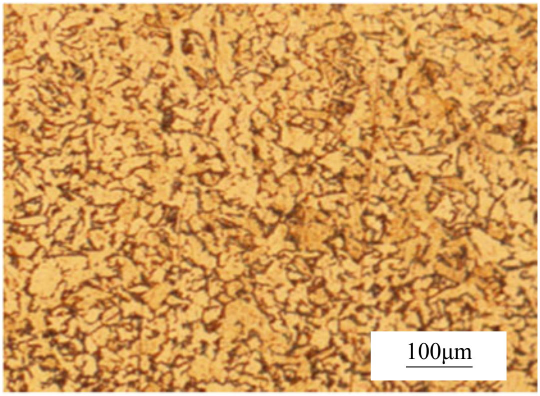
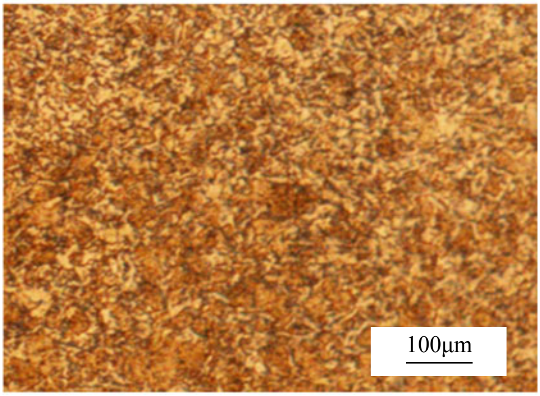


Fig. 5 Arc shape of welding speed under different welding current

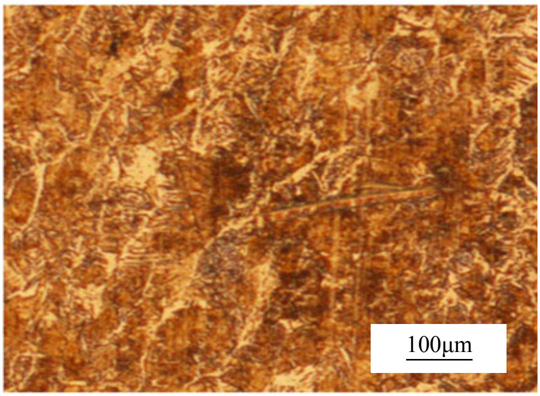
Fig. 6 Microstructure of hybrid weld joint



(a) Base material



(b) Heat affected zone



(c) Central area of hybrid weld

mainly granular bainite and a small amount of martensite. The grains are fine and uniform, and the comprehensive mechanical properties are good.

4 Conclusion

1. Laser DP-TIG hybrid welding can significantly improve the welding speed of thin plate welding on the premise of ensuring the good formation of the weld and has good adaptability to the gap and misalignment.
2. Using hydrogen gas and filler wire in hybrid welding can improve weld formation and welding speed, but the adjustment of wire feeder is complex.
3. In hybrid welding, the welding current and laser power have a certain matching range. The best matching parameters of 2 mm thick plate are about 2500 W laser power and 200 A welding current; The best matching parameters for 4 mm thick plates are about 4000 W laser power and 200 A welding current. If the current is too small, the weld formation is poor, and if the current is too large, the laser will be diluted to reduce the penetration. In high-speed welding, laser power plays an important role in penetration, and welding current is mainly used to improve weld formation and increase weld width.
4. The microstructure of the hybrid weld is mainly bainite and martensite, with fine grains and directionality.

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