Test and Analysis of TIG-MIG Hybrid Welding Arc

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Abstract. A high-speed camera is used to observe the arc starting and arc stabilization process of the TIG-MIG hybrid welding system. Paschen’s law is used to analyze the path of TIG welding arc breakdown under the condition of the conductive channel provided by the MIG welding arc, and the arc starting process of the double arc hybrid welding is determined. The study found that when the electrode spacing is less than 8.5 mm, two molten pools can form a common molten pool after arc initiation of MIG welding; when the spacing is 10 mm, the two molten pools after arc initiation form a "8" shape; When the distance is 12 mm, there is a low temperature zone between the two arcs, which is separated.

Keywords: Hybrid Welding Arc, TIG-MIG Welding, Double Arc, High-Speed Camera.

1. Introduction
In the traditional welding process, the arc burns between the electrode and the workpiece, and a higher deposition rate can be obtained. However, due to the large amount of heat input to the workpiece, it may lead to excessive melting and large welding deformation, and it is easy to cause excessive burning of alloy elements during the welding process, and at the same time cause the welding seam structure to be coarse, and there is a tendency to crack, etc. [1]. Hybrid welding technology has the characteristics of small deformation, large penetration depth and process stability, and can obtain high deposition efficiency with a small heat input, so that the above-mentioned problems have been effectively solved [2-4]. The most widely used methods in hybrid welding are TIG-plasma arc double-sided welding and TIG-MIG double-sided welding.

TIG-MIG double-sided welding is a process that uses MIG welding arc as the main heat source and TIG welding arc as the auxiliary heat source to jointly complete the welding process. Among them, the heat input of TIG welding is smaller, and the heat input of MIG welding is larger. Japan's Hideo Kobayashi et al. [5] conducted an in-depth study on TIG-MIG double-sided welding, which can obtain a smaller penetration depth while ensuring the stability of the arc. Scholars such as Wu Zhiqiang in China have also conducted in-depth research on the single power source TIG-MIG series arc welding process and equipment. The TIG welding arc is used as the front conducting arc, which increases the welding heat input and penetration, on the other hand, it also has preheating. And the role of cleaning up [6]. Russian scholars such as OznamM [7] have shown that the double-arc surfacing metal has the characteristics of fine crystal structure and uniform distribution of strengthening phases. This is because in the double-arc surfacing process, the melting electrode arc can form a certain penetration depth, while the non-melting electrode arc can replenish the alloy for the surfacing layer.
There are few theoretical studies on TIG-MIG hybrid welding. Most of the studies are limited to changing the test parameters, and the universal double-arc welding theory has not yet been established [8-10]. It is precisely because of the lack of systematic theory that it is difficult to make breakthrough progress in welding process parameter setting, method selection, device design, etc., which seriously affects the improvement and promotion of this technology.

2. Experimental Research Methods
The TIG-MIG hybrid welding double-arc welding method is used in the experiment, which mainly focuses on the research of the arc starting and the arc-dimensional characteristics of the TIG-MIG hybrid welding. The hybrid welding system is shown in Figure 1.

![Figure 1. Schematic diagram of TIG-MIG hybrid welding system](image)

In the test, a combination of TIG welding torch + MIG welding torch was used, and an independent power supply was used to control the arcing of the MIG welding torch, and then the arcing of the TIG welding torch. The arc starting process, the arc shape at the moment of arc starting, and the process of interaction changes are recorded by a high-speed camera connected to the computer. Try to use low current welding as much as possible in the experiment, on the one hand, it is to reduce the difficulty of observation, on the other hand, it can also reduce the influence of magnetic bias. In order to effectively utilize the effect of cathode cleaning, both TIG welding and MIG welding used the DC reverse connection method in the experiment, that is, the negative end of the DC power supply was connected to the weldment, and the positive end of the DC power supply was connected to the welding wire. In order to increase the penetration depth and obtain the maximum preheating effect, MIG welding uses the normal vertical welding method, while TIG welding uses the electrode backward tilt method. The test uses the Fastcam Ultima 512 model high-speed camera equipment of Photron Company, and uses the iodine tungsten lamp as the backlight source. The frequency is 2000 fps; the shutter is set to 1/8000 s; the resolution is 512×512. During the experiment, the lens was tilted slightly downward, and the aperture was adjusted to the 8 position. Use the equipment to capture the moment of double arc starting and the transition process of arc stable combustion, and analyze the arc shape and interaction process based on the photos taken.

Figure 2 shows the model used for calculation and simulation using Fluent software. The test uses H08Mn2Si welding wire with a diameter of 1.2 mm as the welding material for MIG welding, the base material is Q235 steel, and the angle between the two electrodes is 60°. The parameters set in the test are: welding current 180 A, arc voltage 25 V. Assuming that the size of the workpiece is infinite, A-B and A-C in the figure are the two paths that the TIG welding arc may break down. Paschen's law [11] is used to analyze these two paths.
Figure 2. Simplified model for calculation

3. Test Results and Analysis

3.1 The influence of the distance between TIG-MIG welding electrodes on the arc

The horizontal distance between the two electrodes in the hybrid welding arc is one of the important factors that affect the shape of the hybrid arc. The parameters used in this test are shown in Table 1. In addition, the angle between the two electrodes is 60°, and the welding speed is 8 mm/s.

Table 1. Welding process parameters

| Welding method | Arc voltage /V | Welding current /A | Shielding gas flow / (L·min⁻¹) |
|----------------|----------------|--------------------|-------------------------------|
| MIG welding    | 25             | 180                | 15                            |
| TIG welding    | 20             | 50                 | 20                            |

The formation and morphology of the double arc at 12 mm electrode spacing is shown in Figure 3. (a) Separate MIG welding arc, (b) TIG welding arc ignites on the workpiece, (c) MIG welding arc magnetic bias, (d) 2 unstable arcs, (e) 2 arcs breakdown, (f) 2 stable arcs. It can be seen that when the horizontal distance between the two electrodes is 12 mm, the starting point of TIG welding is on the workpiece. At this time, the TIG welding arc is not stable, and the cathode area deviates from the tungsten electrode axis. This is caused by the TIG welding arc on the workpiece. Caused by the bounce of the upper cathode spot. After the two arcs are broken down, a composite arc is formed, and the combustion state begins to stabilize. At this time, the cathode regions of the two arcs are very close. However, according to the change process of the arc movement, it can still be seen that the MIG welding arc still affects the movement of the TIG welding arc. The cathode spot of the TIG welding arc jumps back and forth between the MIG welding electrode and the workpiece, and the arc is biased to the direction of the welding movement.
When the horizontal distance between the two welding gun electrodes is 8 mm, the formation of the double arc is shown in Figure 4. (a) Separate MIG welding arc, (b) TIG welding arc ignites on the welding wire, (c) 2 arcs breakdown, (d) 2 unstable arcs, (e) 2 unstable arcs, (f) 2 stable arcs. It can be seen that when the hybrid arc is burning stably, the cathode spots of the TIG welding arc formed between the MIG welding wire and the tungsten electrode jump back and forth on the MIG welding wire and the workpiece. At this time, the preheating effect of the TIG welding arc is not very obvious, and the two arcs If the distance is close, there is a phenomenon that the arcs pierce each other to form a compound arc.

When the distance between the two torch electrodes of TIG-MIG welding is adjusted to 10mm, as shown in Figure 5, (a) Separate MIG welding arc, (b) TIG welding arc ignites on the workpiece, (c) TIG welding arc is close to the MIG side, (d) 2 stable arcs. At the moment of TIG welding, the arc is biased towards the direction of welding movement. This is because the TIG welding arc is subjected to the MIG welding arc plasma flow force. The surrounding magnetic field and the fluctuation of the power supply of TIG welding itself. Subsequently, the TIG welding arc gradually approached the MIG welding arc and formed a composite arc. When the composite arc burns stably, the center distance of the two arcs is almost the same as the distance between the electrodes, and the images of the two arcs are very clear.
Figure 5. Double arc formation when the electrode spacing is 10 mm

3.2 Mechanical Performance Test

In the actual welding work, the room temperature is 20°C, the initial temperature of the base material and the welding gun body is 20°C, and the natural convection coefficient of the surface is 3.42 W/(m²•K), the shielding gas for TIG welding and MIG welding is argon, the density of argon is 1.7841 kg/m³, the specific heat capacity is 520 J/(kg•K), and the thermal conductivity is 0.01795 W/(m•K). The argon inlet flow rate is 0.3 m/s, the Q235 steel plate is butt welded, the thickness of the steel plate is 12 mm, the 60° V-shaped groove, and the double arc system in the experiment is used for welding. The tensile specimens used in the test were prepared from welded joint specimens taken from 5 workpieces after welding. The tensile test was carried out on a material testing machine. Table 2 shows the mechanical properties of welded joints under different parameters.

| Electrode spacing/mm | Tensile strength/MPa | Elongation(%) | rate of reduction in area(%) |
|----------------------|----------------------|---------------|-----------------------------|
| Individual MIG welding | 495                 | 16.2          | 46.4                        |
| 7                    | 510                 | 17.1          | 49.2                        |
| 8.5                  | 512                 | 17.8          | 50.4                        |
| 10                   | 518                 | 18.1          | 52.3                        |
| 12                   | 501                 | 16.9          | 48.2                        |

It can be seen from Table 2 that the mechanical properties of the welded joint when the distance between the two electrodes is 10 mm is better than that of other electrode distances. According to the results of the previous test, the arc at this time is in the shape of "8", and the two arcs are in the same molten pool. The TIG welding arc has a good preheating effect on the molten pool of the MIG welding arc, which can reduce the restraint of the welding structure. The welding shrinkage stress is reduced, and the cooling rate after welding can be slowed down at the same time, which is beneficial to the refinement of the weld structure. In addition, the TIG welding arc has a stirring effect on the molten pool, so that the moisture, diffused hydrogen and moisture in the molten pool are smoothly discharged, reducing the generation of cold cracks, and reducing the welding stress and welding strain rate.

When the arc distance is 7, 8.5 mm, the two arcs coincide, and the TIG welding arc has a stirring effect on the molten pool of MIG welding, so that the gas in the molten pool can be discharged smoothly, so the tensile strength of the joint is also higher; When it is increased to 12 mm, the two arcs are separated, so the interaction will be weakened, so the mechanical properties are similar to those of a single MIG welded joint.
4. In conclusion
A high-speed camera was used to observe the arc characteristics of the hybrid welding double-arc at different electrode spacing of the torch, and test according to the actual workpiece, and the following conclusions were obtained:

(1) When the arc distance is 12 mm, the TIG welding arc is affected by the MIG welding arc, and the cathode spot bounces back and forth on the MIG welding electrode and the workpiece, and the arc is biased to the direction of the welding movement; when the distance is 8 mm, the compound arc can burn stably. When the two arcs penetrate each other to form a compound arc, the preheating effect of the TIG welding arc is not very obvious; when the distance is 10 mm, the effect is the best.

(2) Through experiments, it is proved that when the distance between the two electrodes is 10 mm, the shape of the two molten pools presents a "8" shape, and the TIG welding arc produces a good effect on the molten pool of the MIG welding arc. The preheating effect can reduce the restraint of the welding structure, reduce the welding shrinkage stress, and at the same time reduce the cooling rate after welding, which is beneficial to the refinement of the weld structure.

(3) Carrying out the tensile test, when the electrode spacing is 10 mm, the highest tensile strength of the welded joint can be obtained at 518 MPa.

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