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INFLUENCE OF VOLTAGE AND CURRENT ON THE ARC SHAPE IN CABLE-TYPE WIRE TIG-MIG HYBRID WELDING

VPLIV NAPETOSTI IN JAKOSTI ELEKTRIČNEGA TOKA NA OBLIKO OBLOKA MED HIBRIDNIM VARJENJEM S POSTOPKOM TIG-MIG

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In order to achieve high efficiency, energy saving and high quality of welding, it is necessary to carry out research on cable-type wire TIG-MIG hybrid welding. In this study, voltage and current influences on the arc shape in cable-type wire TIG-MIG hybrid welding were studied. The results showed that in cable-type wire TIG-MIG hybrid welding, with an increase in the TIG current, the MIG current increased at first and then remained constant, while the MIG basic voltage remained unchanged. With an increase in the MIG voltage, the TIG current produced small changes, but overall, it remained stable. The TIG current of different droplet-transfer modes had different effects.

Keywords: tungsten inert gas welding, metal inert gas welding, cable-type wire, arc shape, voltage, current

Članek opisuje raziskavo hibridnega varjenja s postopkom TIG-MIG (angl.: Tungsten Inert Gas – Metal Inert Gas) z namenom, da bi ugotovili njegovo učinkovitost, porabo energije in kakovost varjenja. Pri hibridnem postopku varjenja so uporabili varilno žico v obliki pletenice. V članku je opisan vpliv električne napetosti in električnega toka na obliko obloka pri uporabljenem postopku hibridnega varjenja TIG-MIG s pletenico. Rezultati raziskav so pokazali, da z naraščanjem električnega toka TIG, tok MIG najprej narašča, potem pa se njegova vrednost ustali. Osnovna napetost MIG ostane nespremenjena. Z naraščanjem napetosti MIG pride do majhnih tokovnih sprememb TIG toda v celoti le-ta ostane stabilen. Drugačen pa je učinek električnega toka TIG na način prenosa kapljic kovine.

Ključne besede: varjenje v zaščitnem plinu z volframovo elektrodo, varjenje z varilno žico v obliki pletenice, oblika obloka, električna napetost in tok

1 INTRODUCTION

Tungsten inert gas (TIG) welding and metal inert gas (MIG) welding are most popular and widely used in modern manufacturing. TIG welding is a stable welding technology using a tungsten electrode as the anode and argon as the shielding gas.[1] During the TIG-welding process, the arc is stable without spatter and the welding quality is good. However, its welding speed is small and its production efficiency is relatively low, so it cannot meet the requirements of a modern high-efficiency industrial production. MIG welding is performed by melting the welding wire under the protection of argon and using the welding wire as the anode through the arc heat and resistance heat.[2] MIG welding can provide enough heat to melt the welding wire with a high deposition rate and high welding efficiency, but the arc is unstable and prone to spatter during the short-circuit transition process. Efficiency of MIG welding is higher than that of TIG welding; however, MIG welding provides poor strength compared to TIG welding.

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As a new type of welding method, TIG-MIG hybrid welding combines the respective advantages of high-quality TIG welding and high-efficiency MIG welding.[3–5] Under the protection of pure argon, the arc of TIG welding can maintain the stability of the MIG welding arc and make it burn stably, so that the spatter in the welding process is greatly reduced. At the same time, the TIG arc provides enough heat to the MIG arc to make the welding wire melt quickly, reduce the droplet short-circuit transition, make the droplet transition more stable, and improve the welding efficiency while reducing the welding spatter.[6]

However, most of the TIG and MIG welding research mainly focused on a single wire with a diameter below 1.2 mm.[7–9] The cable-type welding wire, which has been invented in recent years in China, is an innovative structure stranding multiple welding wires which can be a flux-cored wire or solid wire.[10] A common cable-type welding wire consists of seven twisted wires, one in the middle and the other six around the central wire. A series of research on cable-type wire arc welding was carried out at the Jiangsu University Science and Technology.[11–15] According to this research, a cable-type wire can be used for GMAW, SAW, electro-gas welding and

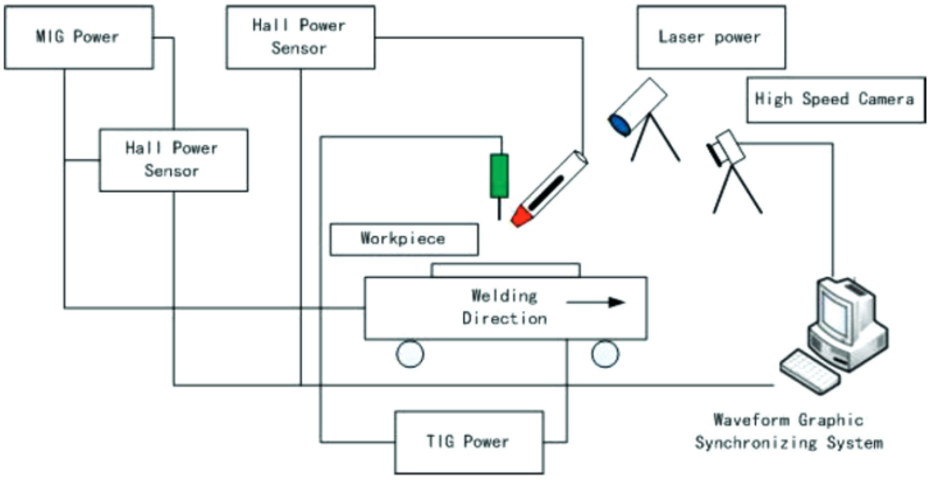

Figure 1: Schematic of the high-speed photography system

hybrid welding. Using a cable-type wire, welding exhibits three significant advantages including high efficiency, energy saving and high quality. Its equipment is simple, easy to use and realize welding automation, and especially suitable for ship-plate welding.

The process of cable-type wire TIG-MIG hybrid welding using a cable-type wire as the filler material and using a composite heat source for welding can effectively improve its efficiency. However, the research of cable-type wire TIG-MIG hybrid welding is still in its initial stage and the welding process parameters for the interactions in welding arc physics are not clearly determined. Therefore, it cannot be widely used in industrial manufacturing. Thus, it was very important to carry out research about the voltage and current influence on the arc shape during cable-type wire TIG-MIG hybrid welding.

2 EXPERIMENTAL PART

A NBC-500 welding machine produced by Chengdu Fukuda Heavy Industry Science and Technology Co., Ltd., was adopted as the MIG welding power source. The adjusting range of the welding current is 50–500 A. In accordance with the current, the voltage matches automatically. It can completely meet the requirements of the experiment. A wire-feeding machine produced by Nantong Zhenkang Machinery Co., Ltd., was used in these experiments. After the wire-feeding machine was modified, it could provide a cable-type welding wire with a diameter from 1.6 mm to 2.4 mm. In order to acquire images of the welding-arc behaviour, droplet-transfer behaviour and molten-pool behaviour, a high-speed video camera with a frame rate of 4000 frames per second was used. A schematic of the high-speed photography system is presented in **Figure 1**.

The welding torch was fixed onto the fixture clamping, made of a horizontal slider, vertical slider and gun body clamp. The relative location of the welding torch was changed by adjusting the horizontal slider and vertical slider and the welding-torch relative angle was changed by adjusting the gun body clamp.

The material was Q235 grade steel, available in sheets of 10 mm. Before welding, metal plates were machined to (300 × 50 × 10) mm by wire-cut electrical discharge machining and faced to prepare the weld surfaces that were cleaned with acetone. The cable-type wire was composed of flux-cored wires and had a diameter of 2.4 mm. It was made of seven fine twisted wires, consisting of E501T-1 with a 0.8-mm diameter. The cable-type welding wire and its cross-section are shown in **Figure 2**. During the welding process, the tungsten electrode was burning easily. In order to reduce the loss of

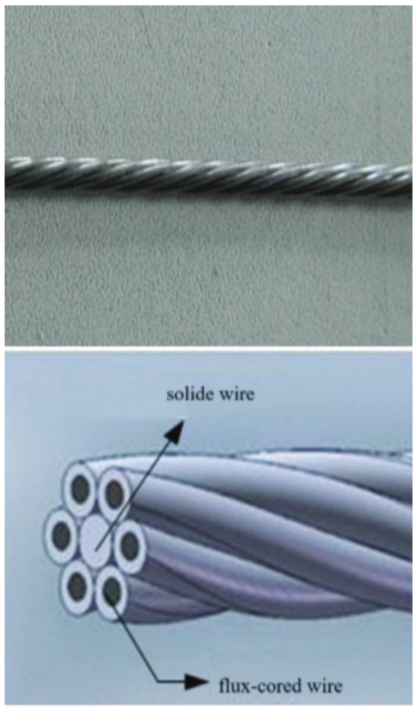

Figure 2: Cable-type welding wire and its cross-section: a) cable-type welding wire, b) cross-section

tungsten electrode, a thorium tungsten electrode with a diameter of 4.0 mm was used.

Based on a series of experiments, the important welding parameters and influence factors of the welding process were determined. The research of cable-type wire TIG-MIG hybrid welding was carried out with the controlling variable method. The TIG welding gun, with the tungsten at an angle of 30°, was perpendicular to the workpiece surface. The length of the tungsten electrode outside the ceramic protective mouth was 5 mm and kept constant. In order to protect the molten pool and stop the protecting gas flow from becoming too large, blowing away the liquid metal from the molten pool, and to reduce spatter, the shielding-gas flow rate of MIG welding was 15 L/min, and the one of TIG welding was 18 L/min.

3 RESULTS AND DISCUSSION

3.1 MIG voltage impact on the TIG-MIG arc shape

During traditional MIG welding, there was a directly proportional relationship between the wire feeding speed and the welding current. The wire feeding speed was changed by adjusting the welding current. The greater the welding current, the faster was the wire feeding speed. The MIG voltage was mainly used to adjust the welding-wire melting speed. The wire was melted faster when the MIG voltage was high. When the welding current was constant, the wire feeding speed was also constant. The MIG arc length was adjusted by changing the MIG voltage. The length of the MIG arc directly affects the coupling form between the MIG arc and the TIG arc.

As shown in **Figure 3**, when the current of TIG was 100 A and the distance between TIG and GMAW arc was 18 mm, it was observed that by changing the MIG voltage, the droplet transition was mainly short-circuit transition, the MIG arc length was shorter, and its length was 4 mm when the MIG voltage was 20.2 V. The TIG arc force was mainly at the bottom of the arc. With the axis of the tungsten electrode, the overall TIG arc shifted in the direction of the welding wire, surrounding the MIG arc. The TIG arc can effectively improve the conductive environment of the MIG arc, making the MIG arc flame more stable and the melt dripping transition more smooth, thus reducing the welding spatter effectively.

When the MIG voltage increased to 28.1 V, the arc had the shape shown in **Figure 3d.** It was clear that the MIG arc became significantly longer, and the droplet transfer included small particles. As the MIG arc length increased, its attraction to the TIG arc was markedly enhanced. The TIG arc and MIG arc were tightly coupled, and the coupling arc shape was trapezoidal so that the channel between the arc areas greatly increased. During this process, necking occurred during the droplet transition. The MIG arc produced a brief contraction and at the same time, the MIG arc was separated from TIG arc. After the droplet transfer to the pool, the two arcs were

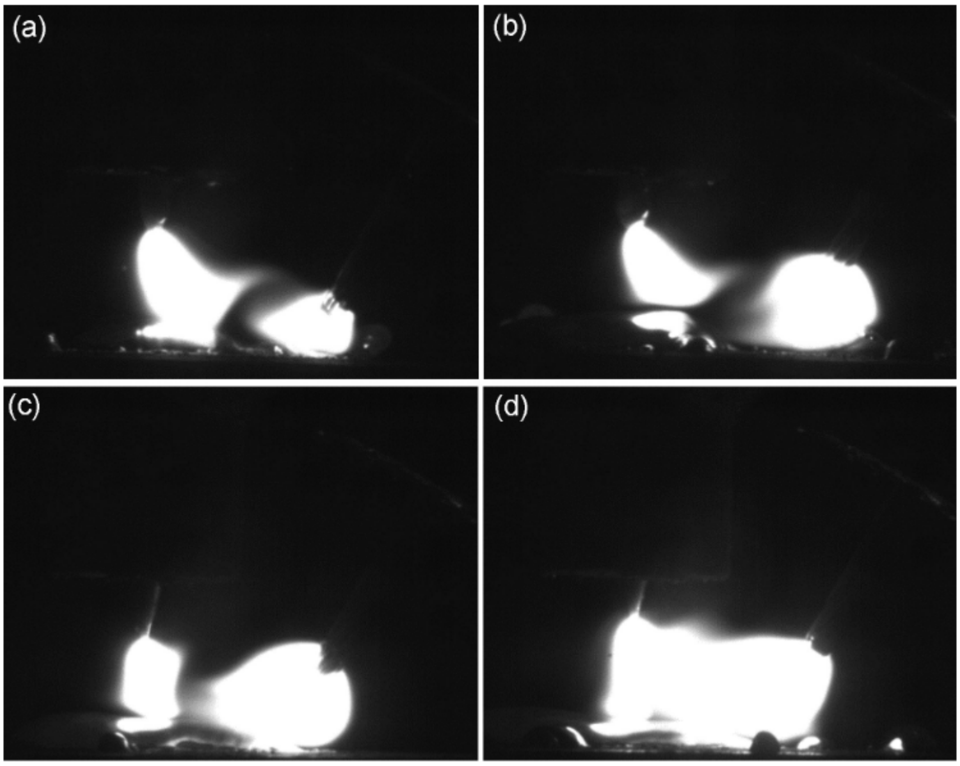

Figure 3: Influence of U_{MIG} on the arc shape of composite welding (I_{TIG} = 100 A): a) U_{MIG} = 20.2 V, b) U_{MIG} = 23.5 V, c) U_{MIG} = 26.7 V, d) U_{MIG} = 28.1 V

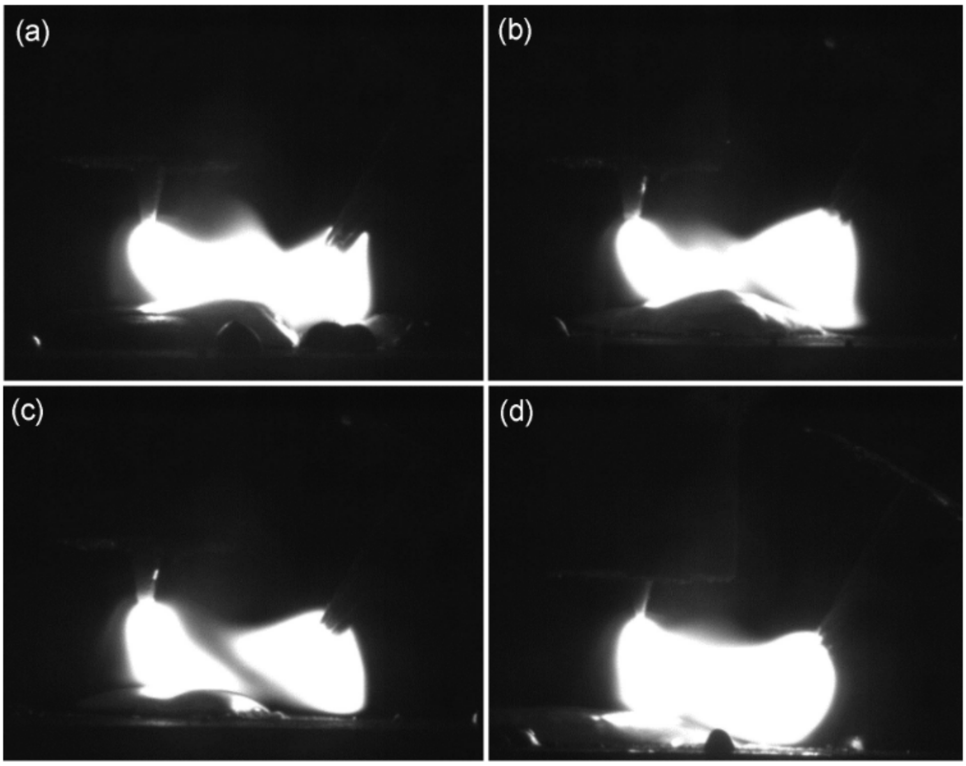

Figure 4: Influence of U_{MIG} on the arc shape of composite welding (I_{TIG} = 160 A): a) U_{MIG} = 23.1 V, b) U_{MIG} = 25.8 V, c) U_{MIG} = 29.1 V, d) U_{MIG} = 32.4 V

coupled together. During this period, the MIG arc continued to rotate to stir the molten pool, which fully released the gas. At the same time, the TIG arc was continuously heating the pool, increasing the molten-pool solidification time; as a result, the welding blowhole defect was greatly reduced. It not only improved the efficiency of welding but also ensured the welding quality.

As shown in **Figure 4**, when the current of TIG increased to 160 A and the distance between TIG and GMAW was 18 mm, the TIG arc angle increased along the axis of the tungsten electrode and the impact of the TIG arc on the molten pool was increased by changing the MIG voltage to 23.1 V. The coupling area of the TIG arc and MIG arc increased, and the high-temperature zone of the coupling area affected the molten pool, giving the pool more room to spread out across the workpiece. When a drop was about to fall off, the TIG arc "climb arc phenomenon" could appear, namely, the TIG arc tail was drawn to the MIG arc above the wire end. With the increase in the MIG voltage, this "climb arc phenomenon" become more obvious. It was because the MIG arc current density was at the end of the wire during the molten-droplet necking period. Therefore, the attraction was larger for the TIG arc.

3.2 TIG current impact on the TIG-MIG arc shape

The stability of an arc refers to the arc resistance to interference. The arc generally flows along the axis of the electrode and the specific performance with an increase in the welding current enhances its stability; namely, the stability of the arc also increases. In cable-type wire TIG-MIG hybrid welding, the TIG arc was mainly used to increase the stability of the MIG arc in order to reduce the splash. The TIG welding current was greater, the plasma channel area of the TIG and MIG arc formation was larger and the stability of the hybrid arc was better. When the TIG current increased, the TIG arc stability also increased.

Figure 5 shows the influence of TIG on the arc shape of hybrid welding. When the TIG current was 100 A and the MIG welding parameters were 260 A and 26.5 V, the TIG current was smaller and the arc stability was common, thus easily attracted by the MIG arc. The coupling area was mainly concentrated below the TIG arc, making the melting droplet transition difficult because the heat provided by the MIG welding droplet transition was not enough. Hence, the arc coupling effect was poorer.

When the TIG current increased to 140 A, the TIG arc length also increased. Under the attraction of the MIG arc, the whole TIG arc was drawn to the middle part of the MIG arc and the two arcs achieved good coupling. Most of the TIG arc energy could be applied to the MIG arc, which made the MIG arc melting droplet transition more stable.

When the TIG current further increased to 160 A, the TIG arc length also increased so that the attraction of the MIG arc to the TIG arc was not strong enough to exceed the TIG arc stability and the arc coupling was common,

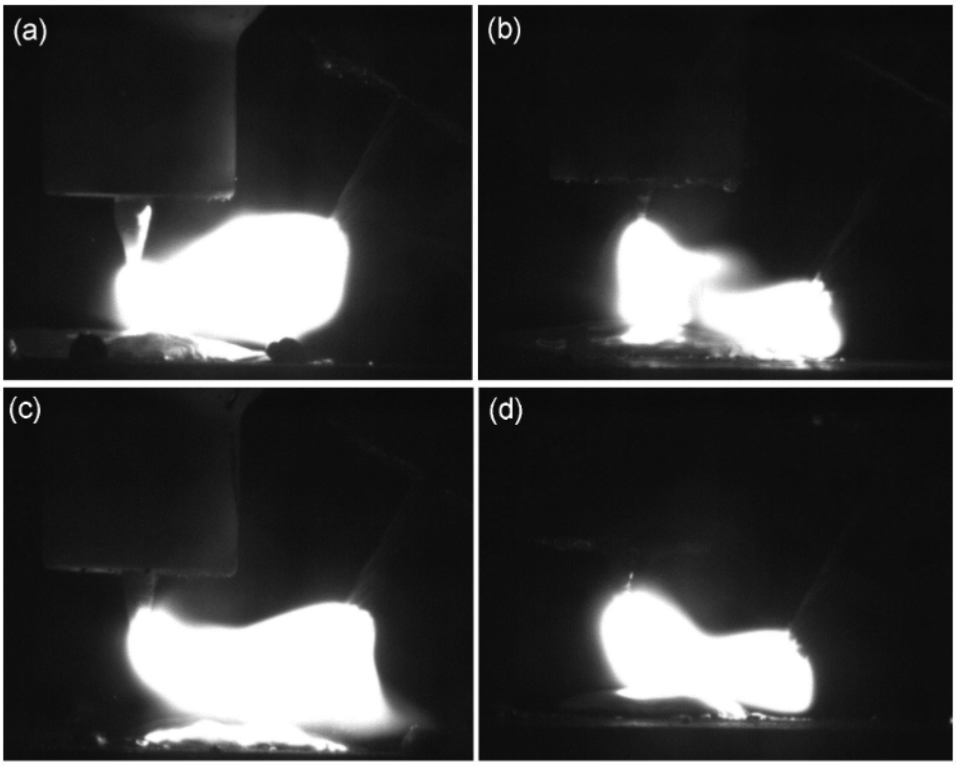

Figure 5: Influence of I_{TIG} on the arc shape of hybrid welding (U_{MIG} = 26.5 V, I_{MIG} = 260 A): a) I_{TIG} = 100 A, b) I_{TIG} = 120 A, c) I_{TIG} = 140 A, d) I_{TIG} = 160 A

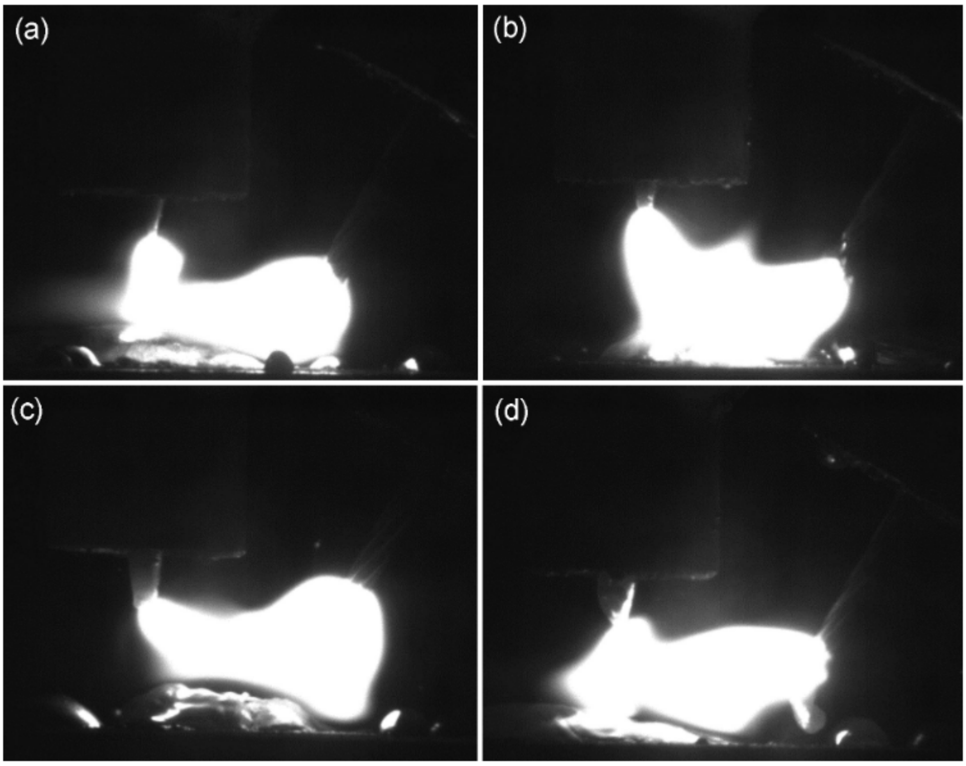

Figure 6: Influence of I_{TIG} on the arc shape of composite welding (U_{MIG} = 29.2 V, I_{MIG} = 300 A): a) I_{TIG} = 100 A, b) I_{TIG} = 120 A, c) I_{TIG} = 140 A, d) I_{TIG} = 160 A, I_{TIG} = (100 and 120) A, b) I_{TIG} = (140 and 160) A

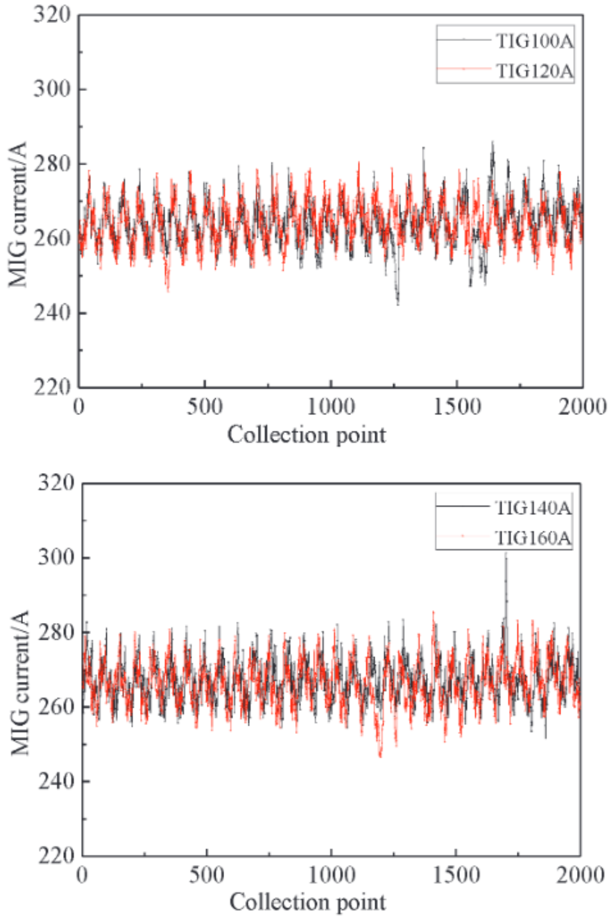

Figure 7: Influence of I_{TIG} on the current waveform of I_{MIG}

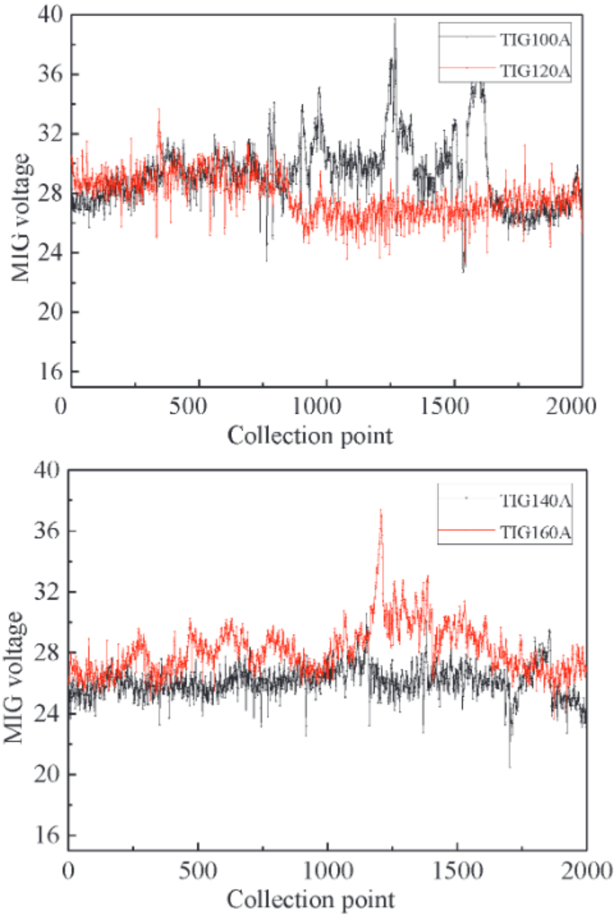

Figure 8: Influence of I_{TIG} on the voltage waveform of U_{MIG}: a) I_{TIG} = (100A and120) A, b) I_{TIG} = (140 and 160) A

exhibiting a smaller enhancement of the MIG welding droplet transfer and arc stability.

When the MIG welding parameters were 300 A and 29.2 V, and the TIG current was in a range of 100–160 A, the hybrid arc had the shape shown in **Figure 6**. The arc length increased with the increase in the MIG voltage. At the same time, the TIG arc exhibited the integrity of deflection. When the TIG current was 100 A, the TIG arc deflection angle was small and the coupling area was concentrated below TIG. The coupling area of the two arcs was in the middle of the arc including the welding wire and tungsten electrode. When the TIG current was 140 A, two thirds of the TIG arc length was attracted by the MIG arc. At the same time, the two arcs reached the best coupling. When the TIG current was 160 A, the MIG arc was drawn and the coupling area was concentrated in the upper part of the TIG arc. In other words, the extreme tungsten-needle loss took place because the heat concentrated easily, leading to a decline in the welding quality.

Figure 7 shows the influence of the TIG current on the MIG current waveform. With the increase in the TIG welding current, the MIG current volatility decreased after increasing first. When the TIG current was 140 A, the MIG voltage stability was the best. As the TIG current continued to increase, the MIG current stability decreased. In general, the stability of the MIG current was better than that of the MIG voltage.

When the MIG welding parameters were 260 A and 26.5 V, the TIG current gradually increased. The TIG current was (100, 120, 140 and 160) A in turn, and the MIG voltage changed as shown in **Figure 8**. When the TIG current was 120 A, it was observed that an increased voltage wave appeared, illustrating that the MIG was relatively unstable. When the TIG current was 120 A, the MIG voltage wave that entered a relatively stable period, exhibited less volatility.

When the TIG current was 140 A, the MIG voltage that had no bigger peaks or troughs achieved the optimal steady state, which was kept at the 26 V range; this showed that the two-arc coupling was good so that the MIG arc could make a full use of the TIG heat for the droplet transition, leading to a good weld from. When the TIG current was 160 A, the two arcs attracted each other more so that the TIG arc could attract the MIG arc thoroughly. However, the two arcs were too disruptive and unstable, which resulted in poor welding quality.

4 CONCLUSIONS

1) The TIG-arc heat source has a compensation effect on the MIG arc so that it can improve the stability of the welding arc and droplet transition in cable-type wire TIG-MIG hybrid welding.

2) During cable-type wire TIG-MIG hybrid welding, the MIG current increased at first and then remained unchanged with the increase in the TIG current, and the MIG voltage also basically remained unchanged. With the increase in the MIG voltage, the TIG current caused a small change. The whole process remained stable.

3) With different ways of the melting-droplet transition, the TIG current had different effects. In the case of a short-circuit transition and droplet transition, the TIG current had a critical range (130–150 A) that could effectively reduce the MIG arc welding-parameter fluctuations. When the melt was in droplet transition, the effect of the TIG current on the MIG welding-arc stability and droplet size was smaller. The TIG double-arc current interference caused a great fluctuation in the MIG electric parameters.

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