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THE STUDY ON PLASMA-MIG HYBRID ARC BEHAVIOUR AND DROPLET TRANSFER FOR MILD STEEL WELDING

Tao Yang[1], Hongming Gao[2], Shenghu Zhang[2], Jingwei Shi[2] and Lin Wu[2]

[1]Southwest JiaoTong University, Chengdu 6100311 Peoples Republic Of China
[2]State Key Laboratory of Advanced Welding and Joining, Harbin Institute of Technology, Harbin 150001, People's Republic of China

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Abstract. Plasma-MIG hybrid arc welding is a promising technology in material processing, and the properties of this method should be well investigated. A power supply and control system for hybrid plasma-MIG arc welding is developed in this paper. Surfacing welding is conducted on low-carbon steel with H08Mn2Si filler metal, and the relationship of droplet transfer, weld appearance with the arc voltage and current are researched utilizing high speed video and voltage/current data acquisition system. The results show that in Hybrid plasma-MIG arc welding process, MIG arc and plasma arc are coupled with each other by sharing the electric-magnetic field, gas plasma zone and filler metal. Self-regulating property can reduce arc voltage and current fluctuation in the droplet transfer stage, and therefore a stable arc and little sputtering are realized. The wettability of base metal and filler metal are enhanced by the pre-heating effect of plasma arc on base metal, so the weld appearance is improved comparing with traditional MIG arc welding. The work can develop the hybrid high efficiency welding theory and are important for Hybrid plasma-MIG arc welding technology in further practical application.

1. INTRODUCTION

Plasma-MIG welding, also known as plasma-GMA welding, was first introduced in April 1972 by W.G.Essers and A.C.Liefkens at Philips Research Laboratory Center of Netherlands [1-3]. It's a hybrid heating source welding method which is composed of plasma arc and MIG arc. Because of its unique welding torch structure, dry extension of electrode is long and the central temperature is high as a result of are compression effect during welding, which leads to high melting rate of wire. During welding, MIG arc, droplet and tip of wire are all surrounded by plasma arc which does not simply play the role of heating wire, but also changes force state of droplet and path of current. Therefore, many characteristics of this method is displayed [4-6], such as high melting rate, stable and spatter free welding process [7-9], fine grain, and high quality welding joint. However, the reason is not yet studied. In this paper, device of plasma-MIG welding is developed to mainly investigate characteristics of hybrid arc, relation among form of droplet transfer, electrical parameters and welding characteristics, which will enrich theory of high efficiency welding leaded by hybrid arc and make benefits to promotion of plasma-MIG welding method.

2. EQUIPMENTS AND MATERIALS

Behavior of plasma-MIG arc and droplet transfer are critical factors affecting the quality of weld. They both have close relation with electrical parameters.Plasma-MIG welding system used in this paper is self-developed as shown in Fig. 1. High-speed camera is applied to catch pictures of hybrid arc and droplet transfer. Welding sequence control and collection of electrical parameters are realized

Corresponding author: Hongming Gao, e-mail: 889268@qq.com

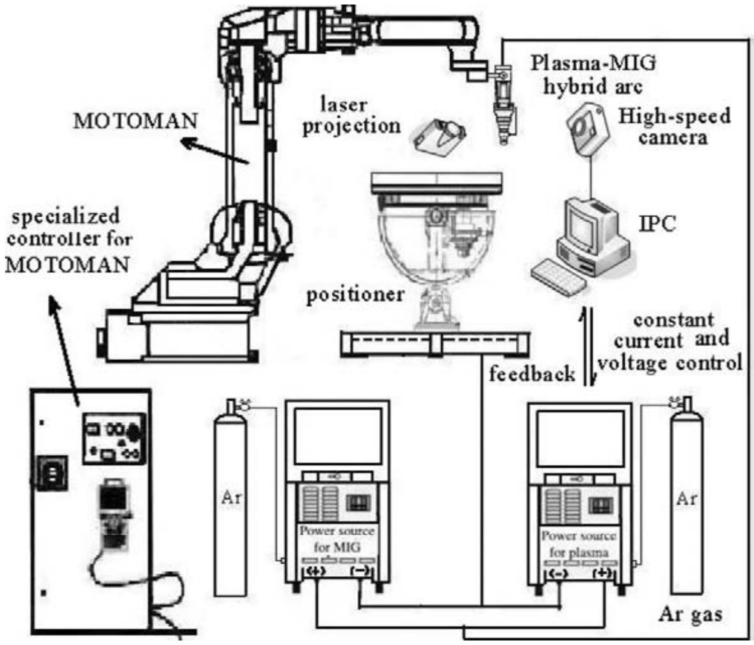


Fig. 1. Rapid prototyping system of Plasma-MIG welding.

by embedded industrial computer. To achieve constant current and current of two welding power source respectively, PID controller is adopt. Welding robot system is in charge of motion of welding torch.

Table 1 shows the composition of base metal (Q235) and filler metal in detail. Low-carbon steel is used for surfacing welding experiment and filler metal H08Mn2Si with a diameter of ö1.2 is adopted.

3. DISCUSSION

3.1. Coupling relation of plasma-MIG hybrid arc

In plasma-MIG welding, MIG arc is burning within plasma arc. Temperature of inner area therefore is 7000-8000K while outside area is 13000K [10]. Plasma-MIG hybrid arc is shown in Fig. 2. Plasma arc and MIG arc do not exist independently, they establish close coupling relation with each other by shared wire, electromagnetic space, and conducting atmosphere. Experiment shows that hybrid arc has self adjust ability and plasma arc is strongly compressed by magnetic field caused by MIG arc. Besides, current originally flowing from MIG arc can bypass to plasma arc, which reduce density of MIG arc and its stirring effect on weld pool.

3.2. Influence of electrical parameters on droplet transfer

3.2.1. Short circuit transfer of droplet in plasma-MIG

Fig. 3 shows how electrical parameters change when short circuit transition happens in plasma-MIG welding. Wire melts at high rate because of plasma arc. Hybrid arc leads to increase of droplet surface

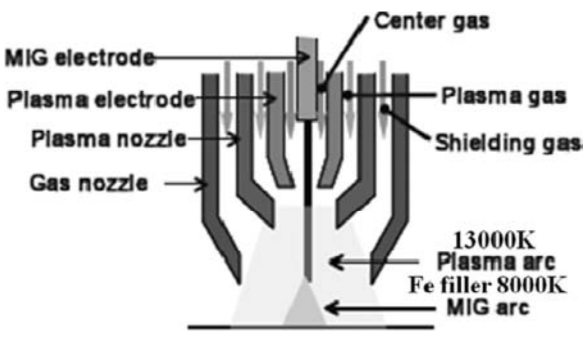
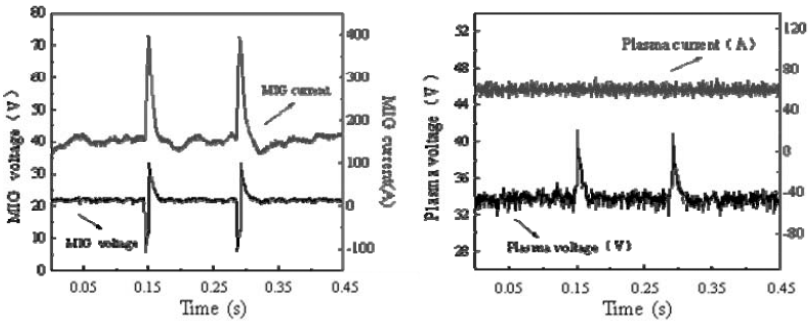


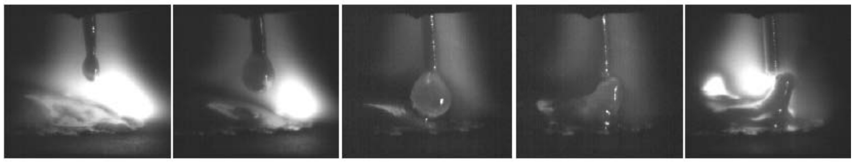
Fig. 2. Plasma-MIG hybrid arc.

Table 1. The composition of base metal and filler metal, (wt.%).

element	C	Mn	Si	P	S	Fe
base metal	5.5~6.8	3.5~4.5	≤0.3	≤0.15	0	remainder
filler metal	≤0.11	1.7-2.1	0.65~0.95	≤0.035	≤0.035	remainder

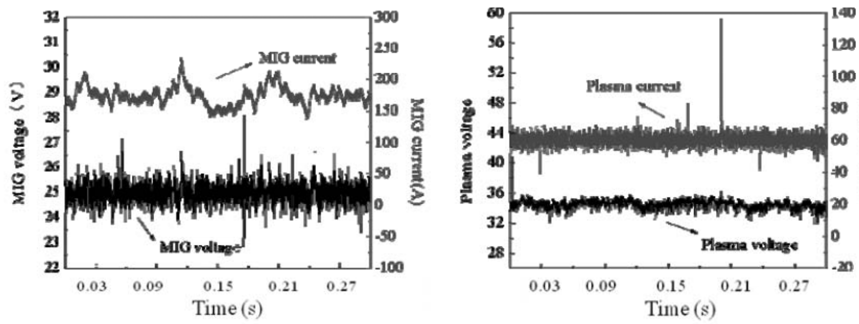


a) b)



c)

Fig. 3. Relation between electrical parameter and short-circuit transfer of Plasma-MIG hybrid arc: a) current and voltage oscillogram of MIG arc, b) current and voltage oscillogram of plasma arc, c) short circuiting transfer with 60 A of plasma current meanwhile MIG voltage is 22 V (wire feeding rate:6.13 m/min).



a) b)

Fig. 4. Relation between electrical parameter and globular transfer transfer of Plasma-MIG hybrid arc: a) current and voltage oscillogram of MIG arc, b) current and voltage oscillogram of plasma arc, c) globular transfer transfer with 60 A of plasma current meanwhile MIG voltage is 25 V (wire feeding rate:6.13 m/min).

tension, enabling it to grow to a large size in time, which makes generation of necking of droplet possible. Therefore, chance of droplet spatter is high lowered. When short circuit happens, MIG arc is distinguished. Voltage drops to 0, but current through wire increase to maximum, which generates great magnetic field around plasma arc, making it to compress. Thus, voltage of MIG current rises as shown in Fig. 3. The whole period of short circuit droplet transfer continues about 0.146 s as calculated from picture caught by high speed camera.

3.2.3. Dropwise transfer of droplet in plasma-MIG

Dropwise transfer of plasma-MIG is shown in Fig. 4. Wire melts at high rate in hybrid arc. Neck of droplet appears when gravity is larger than surface

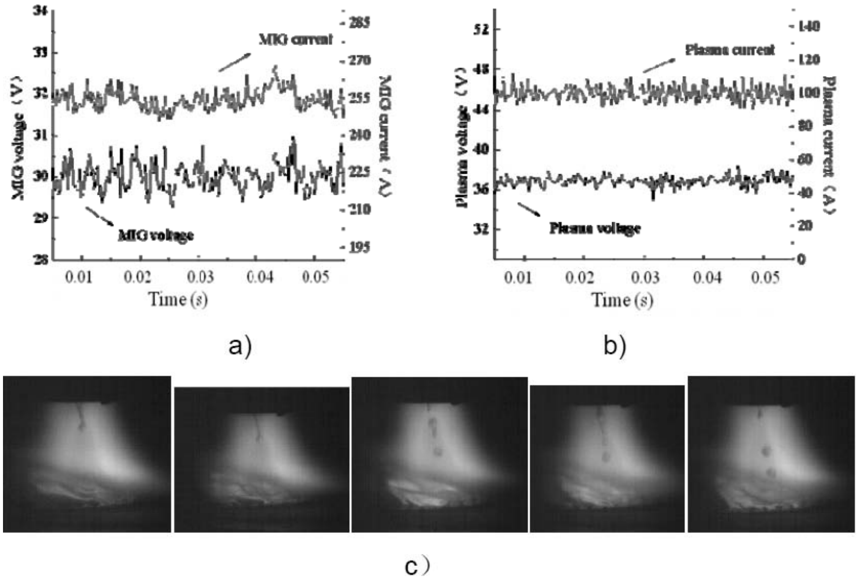


Fig. 5. Relation between electrical parameter and spray transfer of Plasma-MIG hybrid arc: a) current and voltage oscillogram of MIG arc, b) current and voltage oscillogram of plasma arc, c) globular transfer with 100 A of plasma current meanwhile MIG voltage is 30 V (wire feeding rate: 12 m/min).

tension. As droplet is about to transfer when growing, MIG current begins to rise slowly. At the point where droplet transfers to weld pool, MIG current reaches the maximum. Experiments show that plasma arc has strong compression effect on MIG arc, which releases contraction degree of MIG arc. In the whole welding process, hybrid arc is very stable and droplets transfer smoothly. No spatter is detected. Transition period is 0.098 s.

3.2.3. Stream-like transfer of droplet in plasma-MIG

Stream-like transfer of droplet in plasma-MIG is shown in Fig. 5. MIG current and voltage fluctuates at high frequency, demonstrating high transfer frequency of droplet. Pictures caught by high speed camera reveal that lots of small droplets are streaming into weld pool in just 0.3 ms.Additonally, bright and dark layer appears between plasma arc and MIG arc. Outside plasma generated by plasma arc has a relatively high temperature while inner plasma caused by MIG arc is cooler. Difference in temperature leads to difference in brightness. High frequency transfer causes fluctuating of MIG current and voltage. But, stabilize effect of plasma arc on MIG arc makes MIG current fluctuate within small level at high frequency.

3.3. Effect of electric parameters and droplet transfer on weld shaping

Tables 2 and 3 show the weld appearance with different plasma currents when MIG current are 22A and 28A, respectively. A small heat affected zone (HAZ) and big weld reinforcement are observed when

Table 2. Effect of plasma current on weld shaping (V_{MIG} = 22 V).

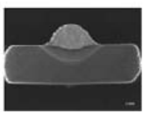
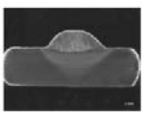
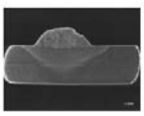
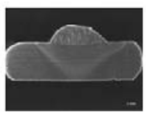
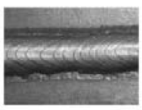
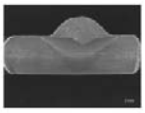
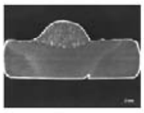
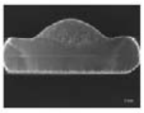
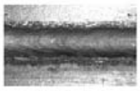
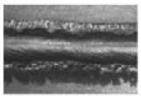
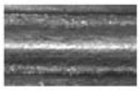
MIG voltage 22 V; wire feding rate: 6.13 m/min; steel and steel				
Parametrs	plasma current 0 A	plasma current 60 A	plasma current 100 A	plasma current 120 A
macro metallography				
weld shape				

Table 3. Effect of plasma current on weld shaping (V_{MIG} = 28 V).

MIG voltage 28 V; wire feding rate: 6.13 m/min; steel and steel				
Parametrs	plasma current 0 A	plasma current 100 A	plasma current 140 A	plasma current 200 A
macro metallography				
weld shape				

plasma current is zero, for a small cross-section of MIG arc compressed by electro-magnetic field, so only the central zone of base metal is melted. Pre-heating effect on the metal surrounding the welding pool by hybrid arc can increase the wettability between the base metal and filler metal, so the weld reinforcement decreases, and the weld width increases. The HAZ increases with the increase of the plasma current. short circuit droplet transfer is the main manner of droplet transfer in a lower MIG voltage at 22 V, and the weld appearance is better than that in a higher voltage at 28 V.

The weld fusion line is smooth when hybrid plasma-MIG arc is utilized, comparing with MIG arc welding, and it indicates that the arc force is almost even in the horizontal direction. High-frequency short circuit droplet transfer observed in MIG arc welding at MIG arc voltage 22 V has the features of big weld reinforcement and poor weld appearance. A better weld appearance with regular and dense scaly figures is available when MIG arc coupled with plasma arc is used. The arc as well as the HAZ expands when the MIG arc voltage increase to 28 V, and the HAZ reaches the back of the base metal when plasma current is 100 A. When plasma current increases to 200 A, the weld is smooth arc straight, while the weld width is not even in other MIG current parameters.

4. CONCLUSIONS

1. MIG arc and plasma arc are coupled with other by sharing the electro-magnetic field, gas plasma and the filler metal. Current separation occurs in hybrid welding process and MIG arc current can also flow through the plasma arc zone via gas plasma and the filler metal, which will reduce the current density and electron-magnetic stirring effect on the welding pool of MIG arc.
2. Arc voltage and current fluctuation induced by droplet transfer in hybrid plasma-MIG arc welding process is suppressed significantly, which can be attributed to the self-regulating effect of hybrid arc properties, so the arc is more stable and sputtering is reduced.
3. Pre-heating effect on the base metal is realized by the hybrid plasma-MIG arc, and the wettability between base metal and filler metal is better, so the weld appearance is more smooth with regular scaly figures.

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