Development of Plasma GMA welding system*


New coaxial plasma GMA welding system has been developed on the purposes of improvement of weld bead, reduction of spatter and fume generation. Welding power sources of GMA and plasma, wire feeding equipment and coaxial plasma GMA welding torch are described in detail. The metal transfer of plasma GMA welding is observed and compared with that of pulsed GMA welding. Although metal transfer in plasma GMA welding and pulsed GMA welding is globular transfer, plasma GMA welding shows smooth metal transfer than that in pulsed GMA welding. Low spatter and low fume welding is realized. The plasma welding current shows high effect on the melting characteristic of Al-Mg alloy wire (A5183-WY), however it shows low effect on that of the mild steel wire (YGW-15). The effect of plasma welding current on bead shape and penetration is examined by bead on plate welding using 4.0 mm thickness Al-Mg alloy sheet and lap joints using 3.2 mm thickness mild steel sheets. With the increase of plasma welding current, the weld bead becomes wide and flat.

Key Words: Plasma, GMA, Plasma GMA welding, Penetration, Arc phenomena, Fume.

1. Introduction

Gas metal arc (GMA) process is the most dominant welding process in various industries of automobile, shipbuilding, and other heavy industries because of the high productivity and low equipment cost. However, spatter and fume generates during welding which are not appropriate for the atmosphere environment and welder’s health. At the same time, the toe angle of weld bead is one of important aspects affecting the fatigue strength of welded structures 1-2).

Plasma GMA welding process has long been suggested since the 1970’s 3). A plasma arc is induced to GMA welding process. When the high electrical conductivity plasma is brought around the GMA wire, the flow electric current from the wire is no longer dependent on its own arc discharge 4). This offers advantages such as increased arc stability, better control over metal transfer and heat input.

However, this plasma GMA welding processing has not been used actually by now. Therefore, authors developed a plasma GMA welding system. The features of plasma GMA welding process are described in this paper.

2. Composition of plasma GMA welding system

2.1 Plasma GMA welding torch

The plasma GMA welding torch is coaxial water cooled torch with 60% duty cycle and 250 A rated output current in both GMA side and plasma side.

The schematic illustration of welding torch is shown in Fig.1. GMA wire is in the center of the torch and connected with contact tip. The circular water cooled plasma electrode is set around the contact tip and insulated with contact tip by a ceramic insulator. There are three gas flow systems using argon gas, argon and dioxide carbon mixture gas. The gas flow for GMA, plasma and shielding nozzle are called central gas, plasma gas and shielding gas, individually. Normally, argon gas is used as central gas and plasma gas. Mixture gas (80%Ar + 20%CO2) or argon gas is used as shielding gas according to materials to be welded. There are three water cooling units employed to cool contact tip, plasma electrode and plasma nozzle with cooling capacity of 246 KJ/min chillers, respectively. The general appearance of plasma GMA welding system is shown in Fig. 2.

2.2 Power source

Two digital control inverter welding power sources are employed as GMA power source and plasma power source. Direct current pulse mode is adopted in GMA side and plasma arc side. The GMA arc length is controlled by the voltage signal feeding back system on the basis of external characteristics in the GMA power source. The pulse peak current, its duration and base current can be adjusted arbitrarily. The plasma power source with constant current characteristic is adopted. Pulse peak current, its duration, base current, duty cycle of pulse peak duration/base duration and pulse frequency can be adjusted arbitrarily. It is possible to control the pulse phase of GMA and plasma as an interface unit is set between two power sources. Direct current electrode positive (DCEP) is adopted in both GMA side and plasma side in this system.
2.3 Wire feeding equipment

A push type wire feeder with alternate current servo motor is adopted. The maximum wire feed rate is 30 m/min. The retract arc start (RS) method is adopted in plasma GMA welding system. The arc start process of plasma GMA welding is as the following sequence. After the signal of arc is switched ON, the wire feeder rotates forward to feed wire. At the same time, no-load voltage is applied between plasma electrode and base metal and a constant voltage is applied between electrode wire and base metal. Once the wire attaches the base metal, wire feeder reverses its rotating direction to retract the wire and the arc forms between electrode wire tip and base metal. When the arc has enough length and the electrode wire tip is near to the plasma electrode, the plasma arc between plasma electrode and base metal starts. At the same time, the wire feeder reversed its rotate direction to feed wire again. By now, the plasma arc and GMA arc are both started.

3. Welding characteristics of plasma GMA welding

3.1 Arc phenomena

The curves of welding current, arc voltage and feature images obtained using a digital high speed video camera of pulsed GMA and plasma GMA welding are shown in Fig. 3. The wire feed rate in both pulsed GMA welding and plasma GMA welding is 10 m/min. The welding current of pulsed GMA is 284 A with the electrode extension of 15 mm using the normal GMA welding torch. The welding current of GMA in plasma GMA welding is 190 A with 125 A plasma welding current and the electrode extension of 30 mm.

In pulsed GMA welding, the arc frame is clear even in the base duration. The arc is unstable when the pulsed GMA current changes from base current to pulse peak current. This is the start stage of spatter formation. It is considered the arc pressure near the wire tip is high because of the arc frame is clear when the welding current at the pulse peak duration as shown in Fig. 3 (A). And the high arc pressure is the resistance of droplet detachment from the wire. This is a reason of spatter formation.

In plasma GMA welding, the GMA arc brightness in base duration is weak, and the plasma is clearly supplied from the nozzle. Especially, the change in the arc frame from the base current to the pulse peak current is extremely smooth as shown in Fig. 3 (B). The diffused edge of arc frame is observed in Fig. 3 (B) on the benefit of plasma arc in plasma GMA welding. Even at the pulse peak duration, the arc frame is not as clear as that in pulsed GMA welding. It can be concluded that there is little metal vapor formed during the pulse peak duration. Smooth droplet detachment is obtained in the pulse peak current. The reason is
that the decentralization of the repelled force for droplet detachment is achieved due to a diffused arc route at the wire tip because the plasma covers the whole surface of the droplet at the wire tip, and then the droplet with the stable plasma atmosphere is seceded by the electromagnetic pinch effect at the pulse peak current. From the voltage changes, it can be concluded that the arc is stable in pulse peak duration and base duration in plasma GMA welding.

The welding process with low spatter comparing with pulsed GMA is achieved by the plasma GMA welding method.

### 3.2 Wire melting characteristics

The relationship between GMA welding current and plasma welding current is shown in Fig. 4 using the mild steel solid wire (YGW-15) of 1.2 mm in diameter at the wire feed rate of 13 m/min. When the plasma welding current is 0 A, the plasma GMA welding is actually pulsed GMA welding and the GMA welding current is 293 A with extension of 30 mm using the plasma GMA welding torch. Although the GMA welding current decreased from 293 A to 240 A when the plasma welding current increased from 0 A to 150 A, the plasma welding current affects the wire melting rate weakly, especially, the plasma welding current over 50 A.

The relationship between GMA welding current and plasma welding current is shown in Fig. 5 with the aluminum wire (JIS A5183-WY) of 1.2 mm in diameter at the wire feed rate of 7.5 m/min. When the plasma welding current is 0 A, the plasma GMA welding is actually pulsed GMA welding and the GMA welding current is 120 A with extension of 30 mm. When the plasma welding current increased from 0 A to 50 A, the GMA welding current decreased from 120 A to 70 A. It means that the preheating effect of plasma arc contributes to aluminum wire melting rate. However, the pulsed GMA welding current
decreases slowly when the plasma welding current increased from 50 A to 125 A. Due to the observation of phenomena during plasma GMA welding, the plasma density around electrode wire has little changed when the plasma welding current is over 50 A.

### 3.3 Weld bead in thin sheet welding

The effect of plasma welding current on bead appearances and cross section of lap joint weld bead using 3.2 mm thickness mild steel plate is shown in Fig. 6. The weld bead shows deep penetration in the center of weld bead and small flank angle at toe in traditional pulsed GMA welding. However, the weld beads show shallower penetration and wider weld width with the increase of plasma welding current in plasma GMA welding comparing with that of pulsed GMA welding.

![Fig. 6 Effect of plasma welding current on bead appearance and cross section](image1)

### 3.4 Weld bead in aluminum welding

The effect of plasma welding current on the penetration and weld bead shape of 4 mm Al-Mg alloy (A5052) welds are shown in Fig. 6 using 1.2 mm in diameter Al-Mg alloy welding wire (JIS A5183-WY) with the wire feed rate of 7.5 m/min and welding speed of 50 cm/min. It shows narrow, high reinforcement and shallow penetration weld bead when the plasma welding current is less than 50 A. The weld width and penetration increase on the benefit of increased heat input by the plasma when the plasma welding current is over 75 A.

The bead appearances and cross section of weld beads achieved by pulsed GMA welding and plasma GMA welding are shown in Fig. 8. The black smut is found outside of cleaning zone around the weld bead. However, clean bead appearance without black smut is obtained by plasma GMA welding independent of plasma welding current. The black smut consists of magnesium oxide, aluminum oxide and aluminum. Because the droplet detaches from the wire tip with low energy and transfers smoothly, the evaporation and oxidization of magnesium and aluminum is suppressed during droplet detachment and metal transfer on the benefit of plasma arc in plasma GMA welding.

As shown in Fig. 8, the clean weld bead as that of TIG and plasma welding can be achieved by plasma GMA welding. The plasma GMA welding can be used on welding of structures, such as motor cycle frame, which is required good bead appearance.

![Fig. 7 Effect of plasma welding current on penetration and bead shape](image2)
4. Conclusions

The new plasma GMA welding system is developed using coaxial plasma GMA welding torch on the purposes of improvement of weld bead appearance, reduction of spatter and fume formation.

The stable metal transfer from the wire tip to the base metal can be obtained because of the smooth change from base current to pulse peak current and smooth droplet detachment.

The clean welding process is achieved on the benefit of plasma arc and smooth metal transfer.

With the increase of plasma welding current, the weld bead becomes flat, and the penetration becomes deep in Al-Mg alloy welding. However, the weld bead becomes flat and penetration becomes shallow with the increase of plasma welding current in mild steel welding.

Reference