Development of Plasma-MIG Hybrid Welding Process

by Nguyen Van Anh*, Shinichi Tashiro*, Bui Van Hanh** and Manabu Tanaka*

This investigation aims to develop a new Plasma-MIG hybrid welding process for butting welding joints of large thickness. In this welding process, Plasma torch and MIG torch are connected in electrode negative (EN) and in electrode positive (EP), respectively. Plasma torch is set up in the leading position, meanwhile the MIG torch is set up in the trailing position. The plasma welding is utilized in keyhole model. The results show that the successful single-sided welding in one pass is fully penetrated. The wettability of welding joints is improved and the penetration is increased in comparison with only conventional MIG welding process and only conventional Plasma welding process. In addition, in order to discuss the research results, the temperature field on the surface of weld pool is also measured. As a result, the temperature on the weld pool surface in Plasma-MIG hybrid welding case is higher in comparison with conventional MIG welding case, especially near the leading edge of weld pool.

Key Words: Plasma welding, MIG welding, Hybrid welding, Wettability, Temperature, Penetration, Weld pool

1. Introduction

Welding is present, in all industrial sectors as a necessary technological process. One of the principal directions for the progress of welding is the development of hybrid welding processes. Plasma-MIG hybrid welding process has developed several decades ago and nowadays, it becomes a bright technology in materials processing. However, due to the interaction of arcs, the phenomena are more complex and stabilizing weld pool is more difficult to achieve compared with conventional Plasma welding and MIG welding processes. Therefore, the deep understanding of formation mechanism of this process are necessary to apply this process in various industry fields for decreasing the cost and improving the quality. In this research, the hybrid welding technology combining the deep penetration characteristics of Plasma Keyhole Arc Welding (PKAW) with the high weld deposition rates of MIG is developed. The arc of PKAW and the arc of MIG are quite different welding heat sources but both work under a gaseous shielding atmosphere at an ambient pressure, making it is possible to combine these heat sources in a unique welding technique. The combination of two processes can be delivered greater welding speed under variable root opening conditions, deeper weld penetration, and be reduced heat input resulting in a narrower heat-affected zone (HAZ) and less distortion.

In this study, Plasma-MIG hybrid welding process of carbon steel plates with 12 mm thickness, square groove and 2 mm root opening has been considered. Furthermore, to discuss the improvement of wettability, the temperature field on the surface of weld pool is also measured in cases of conventional MIG welding and Plasma-MIG hybrid welding. In addition, metal transfer of MIG welding wire and the interaction between the MIG arc and Plasma arc are imaged by a high-speed video camera (HSVC) in order to optimize the welding conditions for this process.

2. Experimental procedure

An experimental setup in this investigation was shown in Fig. 1. Experiment apparatus consisted of a transfer-type plasma arc welding torch (100WH, Nippon Steel Welding & Engineering Co.,Ltd.), a plasma power source (NW-300ASR, Nippon Steel Welding & Engineering Co.,Ltd.), a MIG power source (DP 350, Daihen Co.,Ltd), a wire feeder (CM-7401, Daihen Co.,Ltd), base metal, shielding gas, pilot gas, a HSVC (Memrecam Q1v-V-209-M8, Nac Co.,Ltd), a actuator (THK E56-06-0300H-TS, THK Co.,Ltd), and a band pass filter. MIG power source with the constant voltage characteristic and electrode positive (EP) was set up, meanwhile plasma power with constant current characteristic and electrode negative (EN) was utilized.

A schematic illustration for Plasma-MIG hybrid welding process was exhibited in Fig. 2. As indicated in Fig. 2 (a), two carbon steel plates with square groove and the dimensions of 300 x 50 x 12 mm were employed. The root opening was 2 mm. On the other hand, as indicated in Fig. 2 (b), the configuration of the torches was set up based on the distance between their crossing positions and angle between the electrodes-axis and base metal, thus the leading Plasma and trailing MIG were configured. The tilt angle between MIG torch and Plasma torch was 10 degree. The distance between two torches was 20 mm. The stand of plasma torch was set up at 5 mm. CTWD for MIG torch was set up at 20 mm.

In order to find out the suitable welding conditions for this process, a HSVC was applied to observe the metal transfer from MIG welding wire to the weld pool and the arc interaction.
between MIG welding and Plasma welding at frame rate of 6000 fps. To prevent the very high brightness radiation from Plasma arc and MIG arc, a band-pass filter with the wavelength of 500 nm was fixed in front of camera lens.

In addition, for protecting the backside of welding joints, a back shielding gas box was put on the welding jig. The shielding gas flow was produced into the back shielding gas box for preventing the negative influence of air through two small holes. The back shielding gas flow rate was set at 10 L/min.

Concerning the arc ignition steps, Plasma arc was started firstly and weld pool was formed on the surface of base metal, and then MIG arc was started. In addition, metal transfer from MIG wire filler was imaged by using a HSVC for evaluating the conditions under which the metal transfer was stabilized. The weld bead appearances and the cross-sections were also compared. For each test plate, cross-sections were cut approximately in the middle of the bead. Other welding conditions were expressed in Table 1.

![Fig. 1 An experiment setting up of Plasma-MIG hybrid welding process.](image)

Table 1 Welding conditions.

| Parameters             | Value/Unit |
|------------------------|------------|
| Current                | 180 A      |
| Arc length             | 5 mm       |
| Shielding gas          | Pure Ar/7.5 L/min |
| Pilot gas              | Ar + 10%H2/2.0 L/min |
| Wire speed             | 5.9 m/min  |
| Voltage                | 21 V       |
| Wire diameter          | 1.2 mm     |
| Root opening           | 2 mm       |
| Back shielding gas     | Pure Ar/10 L/min |
| Welding speed          | 18 mm/min  |
| Base metal             | SS400 steel |

3. Results and discussion

In this investigation, the butt-welding of carbon steel plates with 12 mm thickness and square groove was done successfully in single-pass only with full penetration.
Firstly, the metal transfer from MIG wire to weld pool was observed in order to optimize the welding conditions for this process. A typical result was presented in Fig. 4. In which, “one droplet per one pulse” condition was found for achieving stable metal transfer. It was also seen that a part of EP MIG welding current and EN Plasma welding current were connected directly without flowing to the base metal.

In order to affirm the superiority of this welding process, four welding process kinds were carried out. Fig. 5-9 indicated the weld bead appearances and cross-sections in four processes including: (1) conventional MIG welding, (2) conventional Plasma welding, (3) Plasma welding and MIG welding (first pass by Plasma welding and second pass by MIG welding) and (4) Plasma-MIG hybrid welding.

Fig. 5 (a) and (b) portrayed the weld bead appearance in the case of conventional MIG welding. The welding bead was narrow on the top surface and incomplete joint penetration was found on the bottom surface. The cross-section in Fig. 9 (a) presented a poor metallurgical integrity of the weld with lack of fusion between the wire filler and the base metal. The weld face was in excessive reinforcement. The wettability was not good in this case. It caused the stress concentration in the weld and decreases mechanical strength.

Fig. 6 (a), (b) and Fig. 9 (b) displayed the weld bead profile on the top surface, bottom surface and cross-section in case of conventional Plasma welding. Because the root opening was 2 mm, the welding material was insufficient to fill out the weld bead. As a result, the bottom surface was penetrated, but the top surface was not filled.

Two passes welding including first pass by Plasma welding and second pass by MIG welding was also done. The weld bead appearance and cross-section were exhibited in Fig. 7 (a), (b) and Fig. 9 (c). In which MIG wire and the melt base metal filled out both the top surface and bottom surface respectively. Nevertheless, the lack of fusion (region 1 in Fig. 9 (c)) and the incomplete fusion between first pass and second pass (region 2 in Fig. 9 (c)) appeared.

In contrast, in the case of Plasma-MIG hybrid welding, the weld bead profile and cross-section were good. Fig. 8 (a) and (b) expressed the weld bead appearance. The weld bead with good quality on the top surface and with full penetration on the bottom surface was obtained. The cross-section in Fig. 9 (d) exhibited very good metallurgical integrity and consistency of the weld without weld defects such as porosity; crack; lack of fusion; and so forth. The weld was in full penetration and the wettability was good. It can be considered that the stress concentration reduced compared with conventional MIG welding and conventional Plasma welding processes. As a result, the mechanical strength was increased, therefore increased the load capacity of the welding joints. Consequently, the wettability of welding joints was improved compared with conventional MIG welding.

The weld bead on bottom surface in case of Plasma-MIG hybrid welding was a little bit narrower than that in case of conventional Plasma welding. It can be considered based on the interaction between Plasma arc and MIG arc that a current-loop was established between two torches, which reduced downward transportation of momentum and heat of the arc under the plasma arc torch.

In order to explain the improvement of wettability in case of Plasma-MIG hybrid welding, the temperature field on the surface of weld pool was measured. The weld pool surface during welding captured by the thermal camera was shown in Fig. 10 (a) for conventional MIG welding and Fig. 11 (a) for Plasma-MIG hybrid welding. The temperature distribution was indicated in Fig. 10 (b) for conventional MIG welding and Fig. 11 (b) for Plasma-MIG hybrid welding. To discuss the change of temperature along the welding direction on the weld pool surface, the temperature on A-A2 line for conventional MIG welding and B-B2 line for Plasma-MIG hybrid welding were also presented.

In case of conventional MIG welding, the temperature increased from point A (near the tail of weld pool) toward point A1 and decreased from point A1 toward point A2 (near the leading edge of weld pool). The maximum temperature reached to 1960 K at point A1 under MIG wire. In case of Plasma-MIG hybrid welding, the temperature increased from point B toward point B1 and decreased from point B1 toward point B2. The temperature strongly increased around point B1. The maximum temperature reached to 2260 K at point B1.

It can be considered that the total heat input from the arc supplying to weld pool was higher in case of Plasma-MIG hybrid compared with that in case of conventional MIG welding due to difference in total input power.
Fig. 5 Weld bead of MIG welding.

(a) Top surface
(b) Bottom surface

Fig. 6 Weld bead of Plasma welding.

(a) Top surface
(b) Bottom surface

Fig. 7 Weld bead of Plasma welding and MIG welding.

(a) Top surface
(b) Bottom surface

Fig. 8 Weld bead of Plasma-MIG hybrid welding.

(a) Top surface
(b) Bottom surface

Fig. 9 Cross-section of welding joints.

(a) MIG welding
(b) Plasma welding
(c) Plasma welding and MIG welding (two passes)
(d) Plasma-MIG hybrid welding (single pass)
Consequently, the temperature on the weld pool surface was higher in case of Plasma-MIG hybrid welding, especially near the leading edge of weld pool. As a result, the wettability was improved in the case of Plasma-MIG hybrid welding.

4. Conclusions

Plasma-MIG hybrid welding process of thick carbon steel plates was developed. Several main conclusions are shown as follows:
- The temperature on the surface of weld pool in case of Plasma-MIG hybrid welding is higher than that in case of conventional MIG welding, especially near the leading edge of weld pool.
- The welding of carbon steel plates with 12 mm thickness and square groove was achieved by single-pass.
- The wettability in Plasma-MIG hybrid welding case is clearly improved in comparison with conventional MIG welding case.

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