Development of Plasma-Mig Hybrid Welding Process for Butt Joint Welding of Thick Plate Steel

Lam Tran[1*], *Van Anh Nguyen*[2], *Shinichi Tashiro*[2], *Manabu Tanaka*[2], *Thuc Ha Nguyen*[1]

[1]*Hanoi University of Science and Technology - No. 1, Dai Co Viet Str., Hai Ba Trung, Ha Noi, Viet Nam*

[2]*Osaka University, 11-1 Mihogaoka, Ibaraki, Osaka, 567-0047, Japan*

Received: October 06, 2016; accepted: June 9, 2017

Abstract

Welding is present in all industrial sectors as a necessary technological process. One of the principal directions for the progress of the welding is the development of hybrid welding processes. Plasma-MIG hybrid welding was developed several decades ago. Nowadays, it becomes a bright technology in materials processing. One of the versions of the Plasma–MIG processes is basically a combination of a keyhole plasma arc with a MIG arc in order to deliver greater welding speeds, deeper weld penetration, and reduced heat input. In this paper, plate to plate butt joint welds were conducted on mild steel plates and the aims of this research is developed a Plasma-MIG hybrid welding process for single pass welding of thick steel plates. As a result, it was found that the successful single-sided welding in one pass with complete penetration and improve the weldability of welding joints in comparison with MIG welding process.

Keywords: Plasma keyhole, GMAW, Plasma-MIG hybrid welding, Hybrid arc.

1. Introduction

Welding is present in all industrial sectors as a necessary technological process. One of the principal directions for the progress of the welding is the development of hybrid welding processes. Plasma-MIG hybrid welding was developed several decades ago and nowadays, it becomes a bright technology in materials processing. The hybrid welding technology combines the deep penetration characteristics of Plasma Arc Welding (PAW) with the high weld deposition rates of MIG. The arc of PAW 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 possible to combine these heat sources in a unique welding technique. The combination of the two processes can deliver greater welding speeds under variable root opening conditions, deeper weld penetration, and reduced heat input. In turn, lower heat input results in a narrower heat-affected zone (HAZ) and less distortion [1].

Recent years, the interest has been increased in applying PAW process in industry due to the higher welding speeds providing improved productivity and producing welds with high penetration/width ratios. Since, Plasma Laser Technologies (Yokneam, Israel) developed a new hybrid Plasma-MIG welding process that is helping meet the challenges of increased demand, faster cycle times and more efficient manufacturing for tube joining application. This process called Super-MIG, which was recently validated as a viable alternative to GTAW in tube joining application [2]. Jeff Palms has established the hybrid Plasma-GMAW (Super-MIG) weld process as a viable process for welding Titanium. Compared to traditional GMAW welding, this hybrid process dramatically increases welding speed and penetration (both more than double) while producing weld joints with minimal spatter and with superior profile and mechanical properties. Weld joints observed had a high degree of visual and metallurgical quality, free of porosity, cracks and contamination [3]. Emel Taban, Erdinc Kaluc and Alfred Dhooge have investigated the properties of hybrid (Plasma + Gas tungsten arc) welded joints of modified 12% Cr stainless steel conforming to EN 1.4003 and UNS S41003 steels using austenitic stainless steel type of consumables such as 309 and 316 [4]. Welding Solutions from the North American also reported that Plasma-MIG hybrid welding process was able to replace SAW with the hybrid process enabled the 100% joint penetration requirement to be met with single sided welding in one pass on heavy thickness plate of mild steel [1].

However, the explanations given above and from the literature on the Plasma-MIG hybrid welding are still indistinct and are little quantified, as well as mostly dating back to the 1970s and 1980s when the technology available was unable to make the process viable for the industry at that time. Therefore, there is a need to develop new technologies and knowledge for this process. In this paper, plate to plate butt joint welds were conducted on mild steel plates and the

* Corresponding author: Tel: (+84)983.077.322
Email: lam.tran@hust.edu.vn

aims of this research is developed a Plasma-MIG hybrid welding system for single pass welding of thick steel plates. As a result, it was found that the successful single-sided welding in one pass with complete penetration and improve the weldability of welding joints in comparison with MIG welding process. In addition, the metal transfer from MIG wire was imaged by using high speed video camera (HSVC) in order to know the interaction between the plasma arc flow and the MIG arc promotes wire heating and current transfer at the anode spot (at the end of the MIG wire) where the molten weld metal droplets form and subsequently detach.

2. Experimental procedure

The classical representation of Plasma-MIG hybrid welding process was shown in Fig.1. This Plasma electrode establishes an arc at the leading position of the welding process, and a “keyhole” is created within the base material by the plasma arc. GMAW follows and operates typically in the conduction welding mode to fill the void created by the plasma arc. The interaction between the plasma arc flow and the GMAW arc promotes wire heating and current transfer at the anode spot (at the end of the GMAW welding wire) where the molten weld metal droplets form and subsequently detach. The resultant magnetic force F, shown in Fig.1, occurs as a result of the interaction of the electric currents passing through the two electrodes [1].

The experimental apparatus consists of a Plasma torch, a MIG torch, MIG power source with the constant voltage characteristics, plasma source with constant current characteristics and base metal. The configuration of the torches were set up based on the distance and angle between the crossing positions of the electrodes-axis and surface on base metal shown as Fig.2, thus the leading Plasma and trailing MIG were configured. 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 high speed video camera for evaluating the condition under which the metal transfer was stabilized as shown Fig.3.

In order to develop a Plasma-MIG hybrid welding process for single pass welding of thick steel plates, plate to plate butt joint welds were conducted on mild steel plates by varying experimental parameters such as the plate specifications including the thick and initial position of base metal plate, plasma current, the energy input rate of MIG process, the wire feed rate, welding speed. This paper also presents an example of experimental results in which the weld has complete penetration, very good metallurgical, without porosity, cracks, and undercuts in comparison with MIG welding process. The parameters of tests were shown in Table.1 and the initial plate positioning for hybrid welding of plate to-plate butt joints was shown in Fig.2. The bead appearance and the bead cross section of Plasma-MIG hybrid welding and MIG welding was observed using the conventional techniques of macrograph on cross-sections taken from the welded test plates (300 mm bead). For each test plate, a cross-sections was cut approximately in the middle of the bead.

Table.1 Experimental parameters

Parameters	Value	Unit
Base metal	Mild steel; Size: 300x50x9 (mm)	
MIG welding wire	JIS Z3312; Wire diameter: Ø1,2 mm	
Groove angle	45	Degree
Plasma welding current	140	Ampere
MIG welding current	105	Ampere
MIG welding voltage	21	Voltage
Distance between the tip and base metal for MIG	20	mm
Arc length of Plasma	5	mm
Welding speed	12	cm/min
Wire feed rate	240	cm/min
Band pass filter	960	nm
Frame rate	3000	fps
Shielding gas for MIG and Plasma welding	Argon	
Gas flow rate	7.5	l/min
Back shielding gas flow rate	7.5	l/min
The distance between two torches	20	mm
The angle between two torches	10	Degree

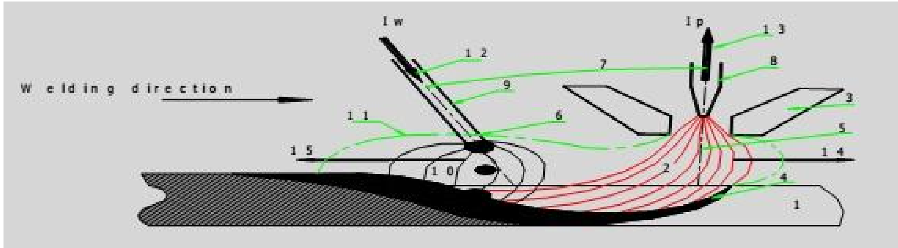

Fig.1 Principle of Plasma – MIG hybrid welding. 1–Work-piece; 2–Plasma jet; 3–Plasma nozzle; 4–Melting metal; 5–Plasma arc electrode axis; 6–Wire axis; 7–Angle between electrode's axes; 8-Tungsten electrode; 9–Consumable electrode (wire); 10–MIG arc; 11–Low temperature plasma; 12–Wire current I_w direction; 13–Plasma current I_p direction; 14—Magnetic forces F applied to plasma arc; 15—Magnetic forces applied to MIG arc

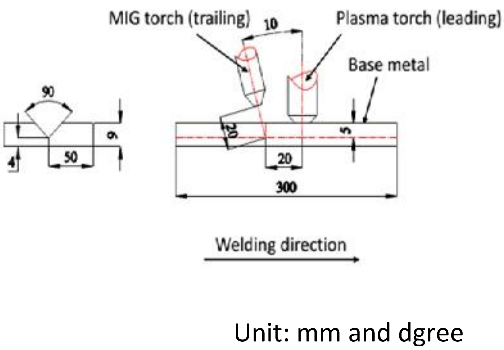

Fig.2 The schematic illustration of the configuration of Plasma and MIG torch

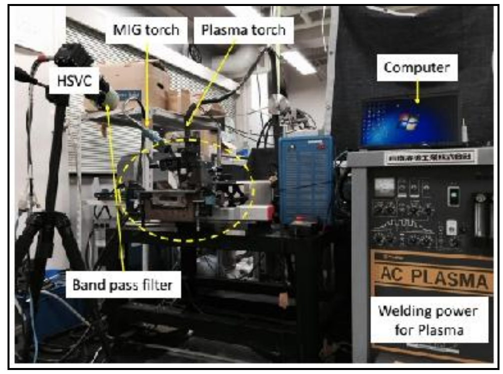

Fig.3 The photograph of the experimental setup including Plasma torch, a MIG torch and the high speed video camera (HSVC).

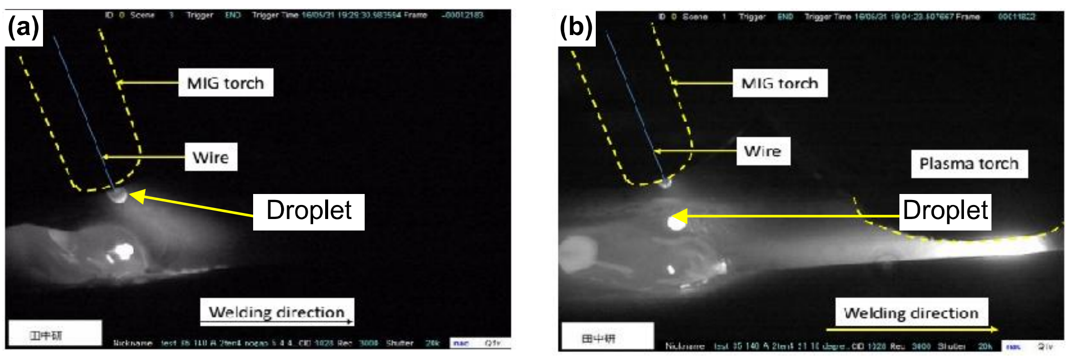

Fig.4 Observation of weld pool and droplet during welding. **(a)** The metal transfer of MIG welding imaged by HSVC; **(b)** The metal transfer of Plasma-MIG hybrid imaged by HSVC.

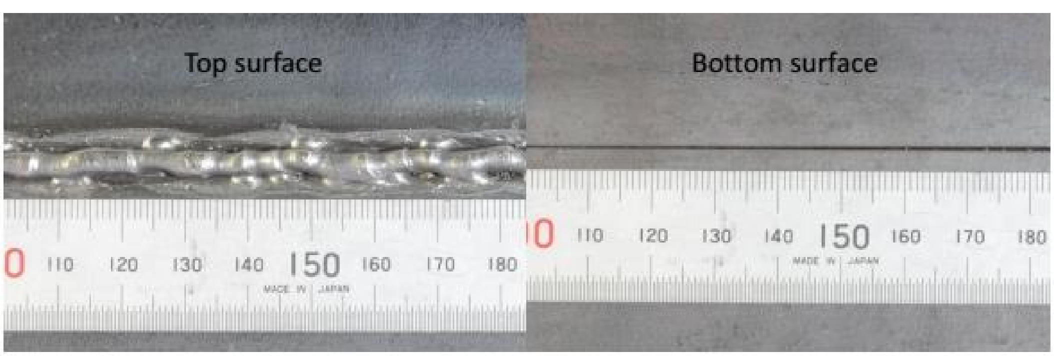

Fig.5 The bead appearance of MIG welding (Welding current: 105 A; welding voltage: 21V; wire feed rate: 240 cm/min; welding speed: 12 cm/min)

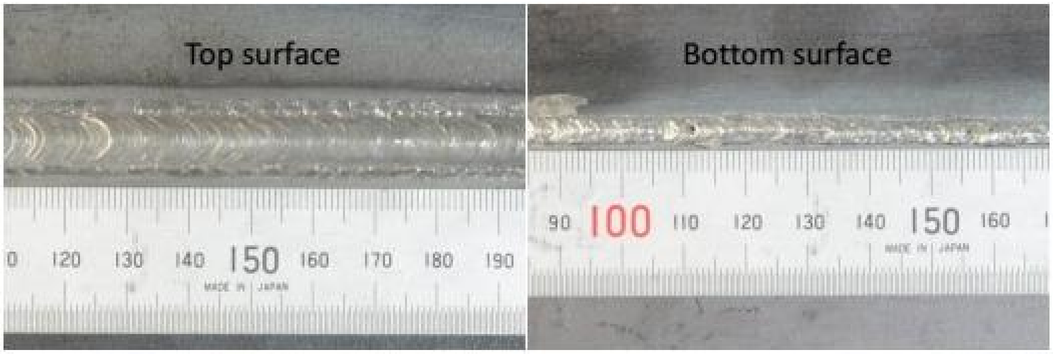

Fig.6 The bead appearance of Plasma-MIG hybrid welding

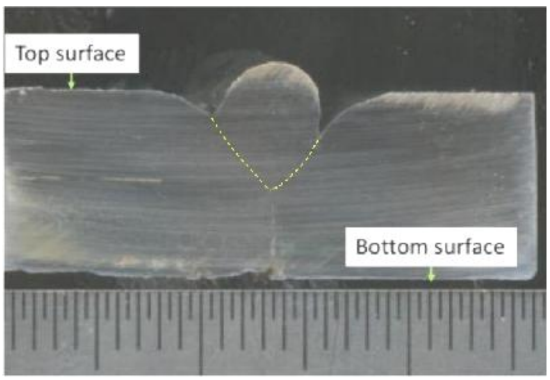

Fig.7 The bead cross-sections of MIG welding (Welding current: 105 A; welding voltage: 21V; wire feed rate: 240 cm/min; welding speed: 12 cm/min)

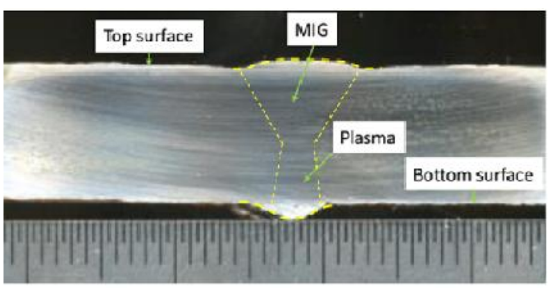

Fig.8 The bead cross-section of Plasma-MIG hybrid welding

3. Results and discussion

The metal transfer of both Plasma-MIG hybrid welding and MIG welding was imaged using HSVC as shown in Fig.4. As seen in the figure the interaction between the plasma arc flow and the MIG arc promotes wire heating and current transfer at the anode spot (at the end of the MIG welding wire) where the molten weld metal droplets form and subsequently detach. The resultant magnetic force F, shown in Fig.1 causes deflection of the plasma arc toward the front of the weld pool, thus compensating for the plasma arc's natural tendency to trail behind the torch axis during high-speed welding. The resultant effect is a substantial increase in the plasma arc rigidity and stability leading to a substantial increase of penetration depth and welding speed.

Fig.5 presents the bead appearance observed by using an optical microscope of MIG welding. The bead with not completed weld bead at the top surface and uncomplete joint penetration at the bottom surface were found because of the heat input of MIG welding process is not enough. Fig.6 presents the bead appearance observed by using an optical microscope of Plasma-MIG hybrid welding. The bead with good quality at the top surface and complete joint penetration with a single pass at the bottom surface were found because of the heat input of Plasma-MIG hybrid welding process is enough.

The cross section of MIG weld illustrated in Fig.7 shows a poor metallurgical integrity of the weld with undercuts at the top surface of the weld and lack of fusion at the bottom surface of the weld. The weld has uncomplete penetration. The cross section of Plasma-MIG hybrid weld illustrated in Fig.8 shows very good metallurgical integrity and consistency of the weld without porosity, cracks, and undercuts. The weld has improved wettability and complete penetration [5].

4. Conclusions

The paper discussed the ability of Plasma-MIG hybrid welding process for butt joint welding of thick plate steel. The following conclusions are deduced from this study:

1) The metal transfer of both Plasma-MIG hybrid welding and MIG welding was imaged using HSVC. As seen in the figure the interaction between the plasma arc flow and the MIG arc promotes wire heating and current transfer at the anode spot (at the end of the MIG welding wire) where the molten weld metal droplets form and subsequently detach. The resultant effect is a substantial increase in the plasma

arc rigidity and stability leading to a substantial increase of penetration depth and welding speed.

2) The Plasma-MIG hybrid welding technology is capable of achieving single-sided complete joint penetration welds of the butt-joint welding of thick plate steel with good weld shape, dimensions, and metallurgical integrity in comparison with MIG welding process.

Acknowledgements

The work was jointly supported by JICA Project (AUN/SEED-Net) with SRJP program and TANAKA's Lab, JWRI, Osaka University, JAPAN.

References

[1] Madison Heights. Hybrid Welding: An Alternative to SAW. Welding Solutions, Inc. (2007).

[2] Plasma Laser Technologies. Hybrid Plasma/MIG Welding Reduces Welding Time. Power Engineering, ProQuest Central. 112(8), (2008) 75-77.

[3] Jeff Palms. Joining Methodologies for Titanium Alloys - Hybrid Plasma and MIG combination. Advanced Industrial Technology, (2004).

[4] Emel Taban, Erdinc Kaluc and Alfred Dhooge. Hybrid (plasma + gas tungsten arc) weldability of modified 12% Cr ferritic stainless steel. Materials and Design. 30 (2009) 4236–4242.

[5] Shinichi Tashiro and Manabu Tanaka. Development of plasma MIG brazing process for dissimilar metal joining of aluminum to steel. International Symposium on Interfacial Joining and Surface Technology (IJST), (2014).