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# Development of plasma MIG brazing process for dissimilar metal joining of aluminum to steel

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**Abstract.** This study aims to develop a new brazing process employing plasma MIG. Because the energy density of the plasma produced by the plasma electrode is low, the base metal can be heated extensively without melting of the base metal, consequently improving the wettability of bead. This paper discussed the dissimilar metal joining of aluminum to steel by plasma MIG brazing process. Fracture occurred at the HAZ in the aluminum plate at 80 MPa.

## 1. Introduction

Dissimilar metal joining of aluminum and steel is significantly important from the viewpoint of the weight reduction of transport systems such as cars, trains, and airplanes. However, since it is difficult to conduct direct fusion joining owing to the formation of a brittle intermetallic compound layer [1], mechanical joining processes using bolts are also still employed. The mechanical joining processes considerably diminish the advantages weight reduction.

Recently, laser welding, which provides excellent energy control characteristics, and FSW (Friction Stir Welding), which enables solid-phase joining, have been adopted for dissimilar metal joining of aluminum and steel [2,3]; however, these processes involve high costs. Therefore, it is necessary to develop simple and inexpensive methods for dissimilar metal joining of aluminum and steel, such as arc process.

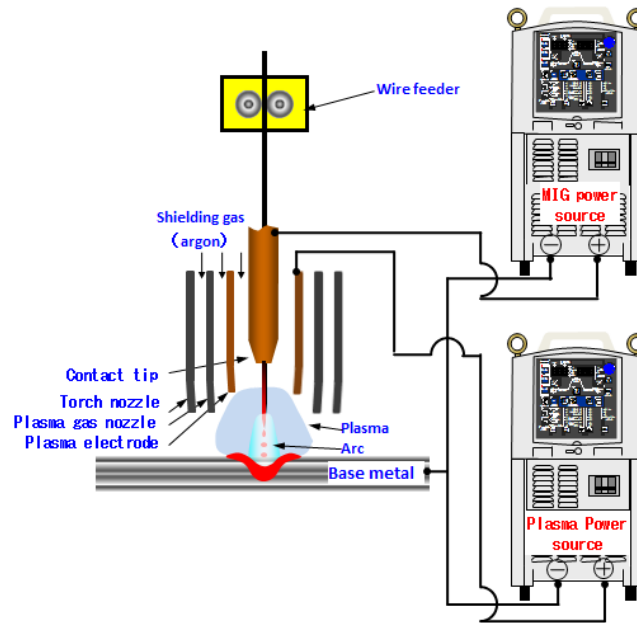
Although MIG blazing is one of the arc processes for dissimilar metal joining processes of aluminum and steel, its practical use is hindered by technical problems that need to be solved. Murakami et al reported that although the dissimilar metal joining of aluminum and steel using flux-cored wire is possible by controlling the heat input appropriately, the use of solid wire increases difficulty owing to low wettability [4].

This study aims to develop a new brazing process employing the plasma MIG process for realizing the dissimilar metal joining of aluminum and steel using solid wire, in order to reduce cost. Figure 1 shows a schematic of the plasma MIG process. Shielding gas is ionized with the plasma electrode before introduction to the arc gap by employing another power source than that for MIG arc, and hence, the shape of the arc is easily controlled by applying electromagnetic force, as shown in Figure 2 [5]. Therefore, the controllability of the arc and the stability of metal transfer in the plasma MIG process are remarkably enhanced compared to the conventional MIG process. Because of this advantage, plasma MIG can be employed for MIG welding in pure inert gas atmosphere. In addition, because the energy density of the plasma produced by the plasma electrode is low, the base metal can be heated extensively without melting of the base metal, thus improving the wettability of the bead.

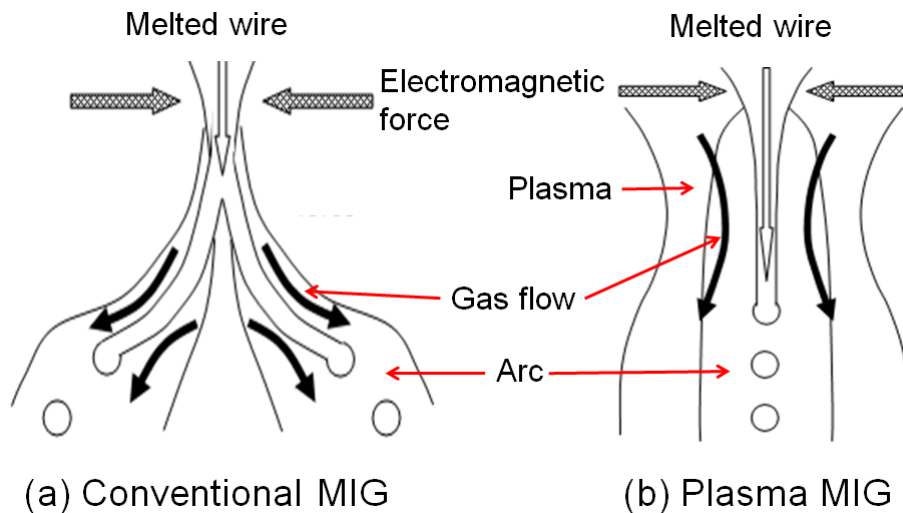


Furthermore, since the oxide layer is cleaned automatically by cathode spots produced on the base metal during the brazing process, a high quality weld joint can be obtained.

This paper discusses the dissimilar metal joining of aluminum and steel plates using solid wire by plasma MIG brazing process conducted for realizing fracture at the HAZ of the aluminum plate in transverse tensile tests of the welded joint.



**Figure 1.** Schematic illustration of plasma MIG process.

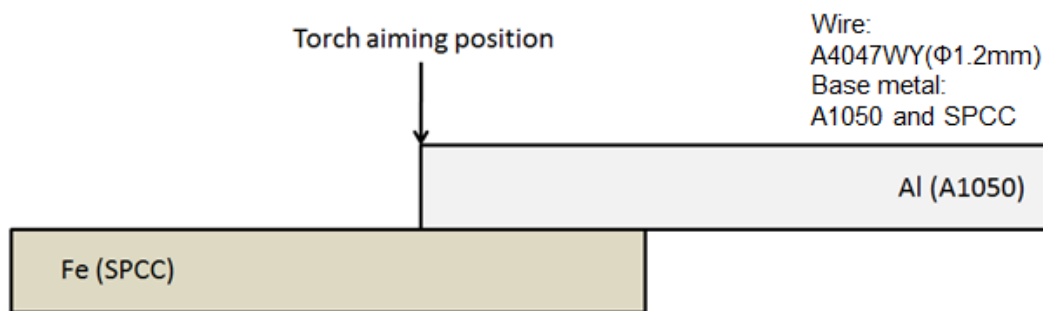


**Figure 2.** Schematic illustration of metal transfer.

## 2. Experimental procedure

The experimental apparatus consists of a plasma MIG torch, MIG power source with constant voltage characteristics, plasma power source with constant current characteristics, and base metal. In addition, metal transfer was imaged using a high speed video camera for evaluating the condition under which the metal transfer was stabilized.

The MIG power source generated the arc through the contact tip (conventional type) between the wire tip and the base metal surface, whereas the plasma power source generated the plasma through the plasma electrode with a diameter of 3 mm. An industrial pure aluminum plate (A1050) and cold rolled plain carbon steel plate (SPCC), with thicknesses of 2 mm each, were used as the base metal. Figure 3 shows a schematic diagram for setting the lap joint between the aluminum and steel plates. The aluminum plate was lapped on the steel plate without gap between both plates. The torch was aimed at the edge of the upper aluminum plate. Solid wire A4047WY with a diameter of 1.2 mm was employed as the electrode wire. A4047WY had a composition of Al-12.0%Si, which is suitable for suppressing growth of the intermetallic compound layer [4].



**Figure 3.** Schematic diagram for setting lap joint between aluminum top plate and steel bottom plate.

## 3. Results and discussion

Figure 4 shows metal transfer imaged using the high speed video camera. As seen in the figure, weak plasma was generated around the bright MIG arc under the wire tip, and the stability of the metal transfer was remarkably improved by the influence of electromagnetic force owing to the plasma current in pure argon atmosphere. Furthermore, many cathode spots were produced on the base metal surface and cleaned the oxide layer on the surface.

In order to realize the fracture at HAZ of the aluminum plate in transverse tensile tests for evaluating the shear strength of the welded joint, brazing tests were conducted by varying experimental parameters such as the wire feed rate, welding speed, voltage of the MIG power source, and plasma current.

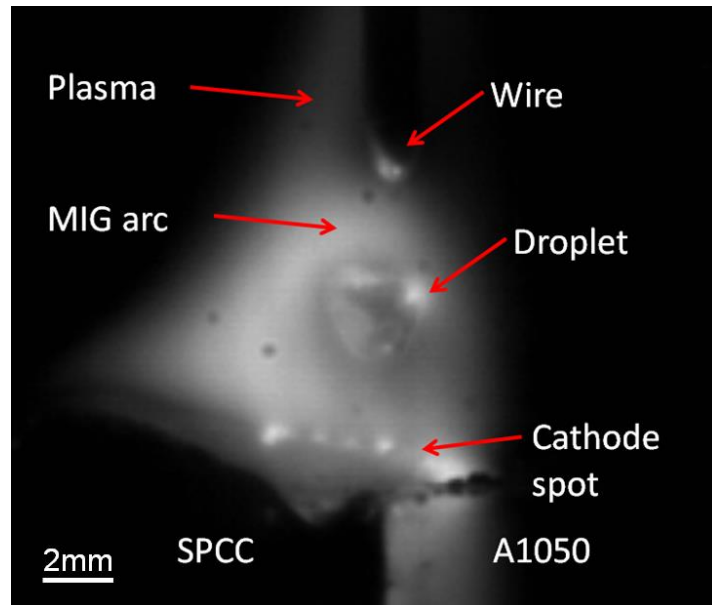
This paper also presents an example of experimental results in which fracture at the HAZ of the aluminum plate occurred. The distance between the torch and the base metal was 10 mm, the wire feed rate was 2 m/min, the welding speed was 60 cm/min, the setting voltage of the MIG power source was 20 V, the plasma current was set to be 20 A, the shielding gas composition was pure argon, and the gas flow rate was 25 L/min.

Figures 5 and 6 show the bead appearance and the bead cross section observed using an optical microscope. The bead with high wettability was found to be obtained because of heating of the steel plate by the plasma.

Figure 7 shows the microstructures observed using an SEM (Scanning Electron Microscope) and the composition observed using an EDX (Energy Dispersive X-ray) spectroscope near the interface

between the weld metal and the steel plate. The average thickness of the intermetallic compound layer was approximately 2  $\mu\text{m}$ , which was less than the upper limit thickness of 2.5  $\mu\text{m}$  required for fracture at HAZ in the aluminum plate previously reported [4] and was in Al-Fe-Si ternary phase.

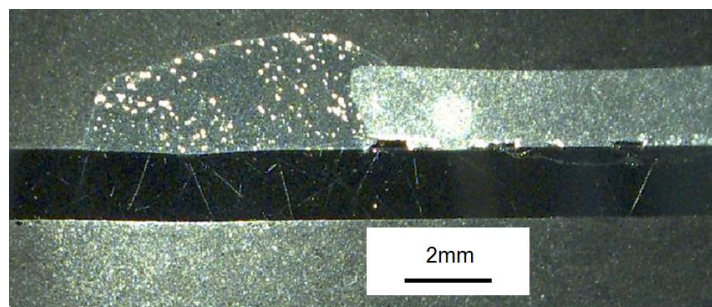
Figures 8 and 9 show the results of the transverse tensile test of the welded joint and a fractured joint, respectively. It was confirmed that the fracture of the welded joint occurred at the HAZ in the aluminum plate at approximately 80 MPa.



**Figure 4.** Metal transfer imaged using high speed video camera.



**Figure 5.** Bead appearance.



**Figure 6.** Bead cross section.

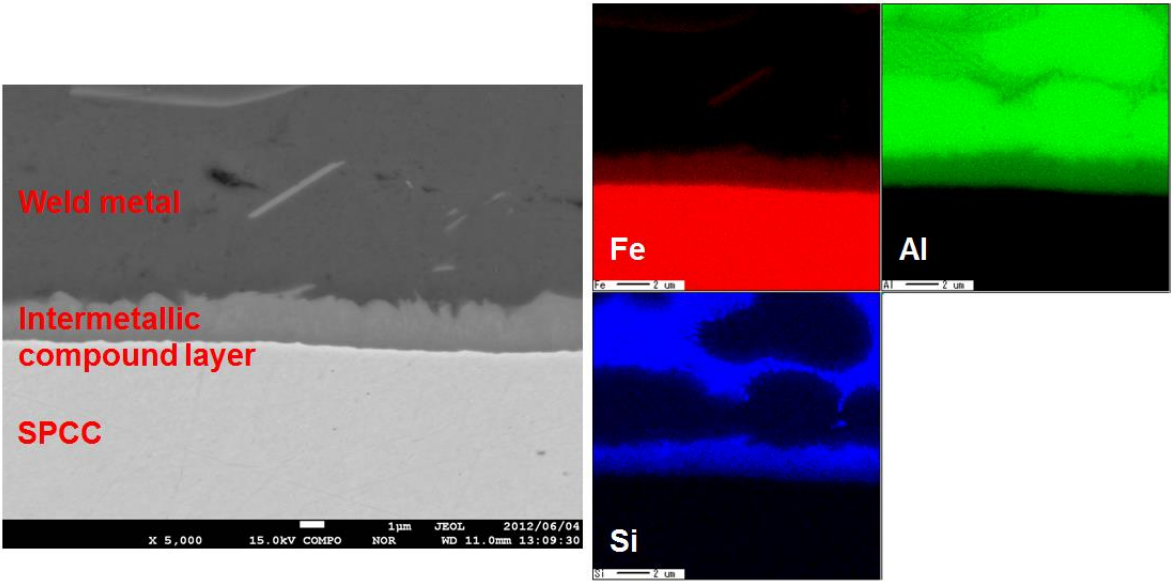


Figure 7. Microstructures and composition near interface between weld metal and SPCC.

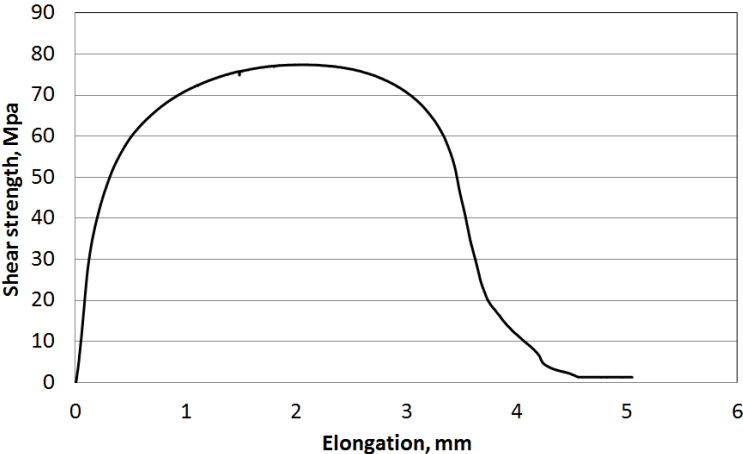


Figure 8. Dependence of shear strength on elongation.



Figure 9. Fractured joint.

#### 4. Conclusions

This paper discussed the dissimilar metal joining of aluminum and steel plates using solid wire by plasma MIG brazing process conducted for realizing fracture at the HAZ of the aluminum plate in transverse tensile tests of the welded joint. The main conclusions are summarized as follows.

- 1) A bead with high wettability was obtained because of heating of the steel plate by the plasma.
- 2) Average thickness of the intermetallic compound layer was approximately 2  $\mu\text{m}$ , which was less than the upper limit thickness of 2.5  $\mu\text{m}$  required for fracture at the HAZ in the aluminum plate previously reported.
- 3) As a result of the transverse tensile test of the welded joint, the fracture of the welded joint occurred at the HAZ in the aluminum plate at 80 MPa.

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