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Dissimilar Metals Welding of Galvanized Steel and Aluminum†

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Abstract

Dissimilar metals joints of galvanized steel (GI steel) and pure aluminum (A1050) were produced using the laser pressure welding method. In this method, dissimilar metals sheets were set between twin rolls. These sheets were opened to make up a wedge-shaped-gap. A 2 kW YAG laser beam was irradiated into the wedge-shaped-gap by a f:θ lens and scanned at various frequencies and patterns using two dimensional scanning mirrors. Then the sheets were pressed by the pressure rolls to be joined.

The welding of the GI steel and A1050 were carried out. In order to investigate the effect of a zinc plated layer thickness on the weldability, GI steel of plated layer thickness of two types were used, and plated layer thickness were about 1.7 μm and 2.6 μm.

The laser pressure welding experiments conducted by changing the laser power and the roller pressure indicated that welding is possible under some conditions. The intermetallic compounds were observed by optical microscope, and the layer thicknesses were measured. The intermetallic compound layer thicknesses increased according to the increase in the laser power and the roller pressure, and the thicknesses of the compound layers were about 3 μm to 18 μm. The tensile shear strength and the peel strength of the welded joints were evaluated. In the tensile test, the strengths of the joints yielded in most welded conditions were so high that the fracture occurred in the aluminum base metal. In the peel test, the roller pressure of more than 1.96 kN, the specimen fracture occurred in the aluminum base metal. In order to investigate the joining mechanism of the welded joints of GI steel and A1050, TEM observation of the compound layer was carried out to examine the reason why the high joint strength was obtained even if the compound layer was thick. From TEM observed results, the joints consisted of the intermetallic compounds mainly, and the Zn phases were formed between the intermetallic compounds. In this research, even if the main constitution phases were the intermetallic compounds, the high joint strengths were obtained because Zn phases formed in the grain boundary of intermetallic compounds.

KEY WORDS: (Dissimilar metals welding), (Laser), (Galvanized steel), (Aluminum)

1. Introduction

Recently, from the environmental preservation or energy saving point of view, the application of aluminum and steel is desired for structural materials in the automobile industry. Especially, the establishment of joining method for the combination of Zn-coated steel and aluminum is desired. The welding of Zn-coated steel and aluminum was examined by the various welding methods [1-5]. The authors performed welding of galvannealed steel (GA steel) and commercially available pure aluminum (A1050) by the laser pressure welding method by changing the laser power and the roller pressure in the previous experiment.[6] In this study, a key to this joining is to utilize a wide range of solid-solution of Zn in Al. It was revealed that dissimilar metals welding of GA steel and pure aluminum was feasible over a wide range of welding conditions. The compound layer thicknesses in the weld interface were in the range of 7 to 20 μm. When the roller pressure was more than 1.96 kN at the laser powers equal to or less than 1400 W, the joint strengths were so high that the specimens in the tensile shear and the peel tests fractured in the A1050 base metal. Even if the compound layer was thick, high joint strength was obtained. In order to know the reason for such high strength of the joints with thick compound layers and the joining mechanism, the compound layer was observed by the HR-TEM. The TEM observation results revealed that the main phase in the compound layer was the solid solution of Al + Zn. The surfaces of A1050 and Zn plated layer were melted thinly, the layer was over 10 μm thicker. The reason for the production of high strength joints with the relatively thick intermetallic compound layer was attributed to the formation of (Al + Zn) phase with finely dispersed intermetallic compounds.

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Table 1 Chemical Compositions of Zn-coated steel and A1050

	C	Mn	P	S	Fe	
GI steel	≦0.15	≦0.80	≦0.05	≦0.05	Rem.	
	Si	Fe	Cu	Mn	Mg	Al
A1050	≦0.25	≦0.4	≦0.05	≦0.05	≦0.05	Rem.

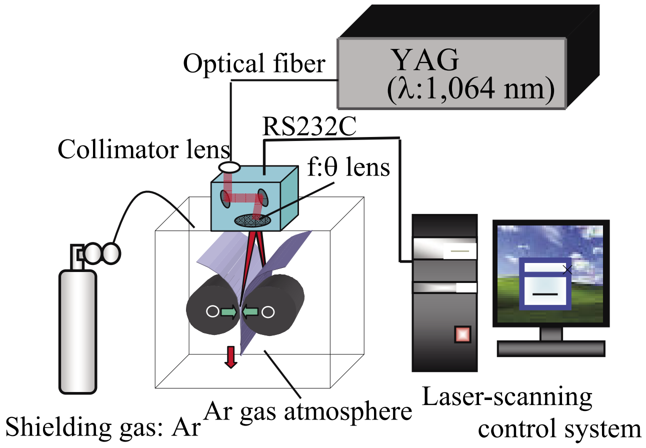


Fig. 1 Schematic experimental set-up of laser pressure welding.

In this paper, the laser pressure welding method was used to join GI steel and pure aluminum. The influence of the compound layer on the joint strengths was evaluated, and the welding conditions for good bonding-ability were established.

2. Experimental

The materials used in this study are commercially available galvanized steel (GI-steel) and pure aluminum (A1050). In order to investigate the effect of a zinc plated layer thickness on the weldability, the GI steel of the different plated layer thicknesses were used. The GI steel used for the experiment was SGCC-Z08 (Z08) and SGCC-Z12 (Z12) in Japanese Industrial Standards, plated layer thickness was about 1.7 μm and 2.6 μm. These chemical compositions are shown in **Table 1**. The sheets are 300 mm long, 12 mm wide and 1 mm thick.

A schematic diagram of our experimental set-up is shown in **Fig. 1**. It mainly consists of a 2 kW YAG laser (FANUC, Y2000A), a beam transfer optic unit, a X-Y beam scanner, a f:θ lens and twin pressure rolls.

The laser beam is introduced into the two-dimensional beam scanner by the optical fiber of 0.6 mm in diameter. The laser beam of about 2 mm diameter is irradiated and focused into a wedge-shaped-gap of two dissimilar metals sheets by the scanner using the f:θ lens of 160 mm in focal length. The sheets are heated directly by the focused beam, and are pressed by twin rolls of 24 mm in diameter and 14 mm in width to complete the welding.

Table2 Welding conditions

Laser power (W)	1200 – 1500
Laser scanning speed (Hz)	30
Laser irradiation position	Center
Defocused distance (mm)	±0
Roll pressure (kN)	0.98－2.94
Traveling speed (m/min)	0.6

Prior to the welding tests, A1050 sheet surface on the joining side was cleaned by Emily paper #1500. The oil and moisture on the respective joining surfaces were removed by acetone. The welding conditions utilized are given in **Table 2**. Two belt sheets were set between twin rolls, by which the pressure was laid on. Moreover, two belt sheets were opened to make up the wedge-shaped-gap and the laser beam went into the gap. During welding, an argon gas flowed for purging air to prevent oxidization at the joining interface. The welded sheet was cut longitudinal to the feeding direction and etched by 3 % nital for observing microstructure of the welded interface.

The mechanical properties of welded joint were evaluated by the tensile shear test and the peeling test. The test piece was laser-pressure-welded joint of 12 mm width. The joint strength tests were carried out using an Instron tensile test machine in atmospheric air. The tensile speed was 10 mm/min.

The welded interfaces were observed in detail by using a scanning ion microscope (SIM), a transmission electron microscope (TEM) and a scanning transmission electron microscope (STEM). Moreover, the compositions distribution near the joint interface was measured by using the energy dispersive x-ray spectrometer (EDX) with STEM. The sample of 60 nm in thickness for TEM observation was prepared using the focused ion beam (FIB) technique. The electron diffraction spot size and the EDX spot size were 3 nm and 5 nm, respectively.

3. Results

3.1 Observation of welded interface by optical microscope

The laser pressure welding of the GI steel and A1050 was possible under some conditions. **Fig. 2** shows the optical microscope photographs near the welded interface. The thick compound layers are seen in the welded interface. **Fig. 3** shows the results of measurement of the thickness in the compound layer. The 3 points average thicknesses of the compound layers on all welded conditions were about 3 μm to 18 μm. The compound layer thicknesses increased according to the increase in the laser power and the roller pressure. The compound layers were thicker than Zn plated layer thickness.

Fig. 2 Optical microstructure near welded interface

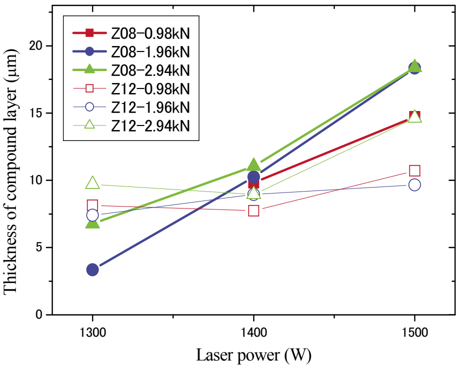


Fig. 3 Relations of laser power, roller pressure and compound layer thickness

3.2 Results of tensile shear tests and peel tests

Fig. 4 and **5** show the results of the tensile shear tests in Z08 and Z12, respectively. In the tensile shear test results, a high joint strength to fracture from the A1050 base metal was obtained under all welded conditions. The peel strengths of the laser pressure welded joints were evaluated. **Fig. 6** and **7** show the results of the peel tests in Z08 and Z12, respectively. The fracture occurred in A1050 base metal when the roller pressures were more than 1.96 kN. In this instance, the strengths of the joints were so high that the fractures occurred in the Al base metal at the tensile shear tests and the peel tests.

From these results, the influence of the plating layer thickness of Zn on joint strength was not seen. It was also confirmed that the GI steel and A1050 joints with good weldability and high joint strength were produced by the laser pressure welding.

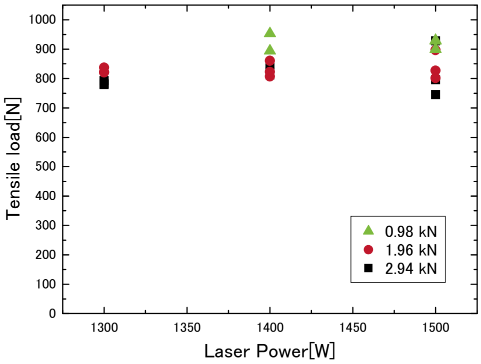


Fig. 4 Tensile shear test results of Z08.

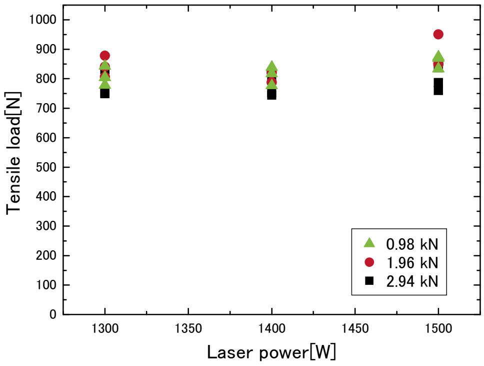


Fig. 5 Tensile shear test results of Z12.

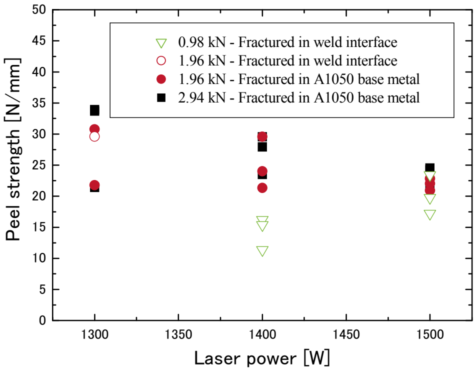


Fig. 6 Peel test results of Z08.

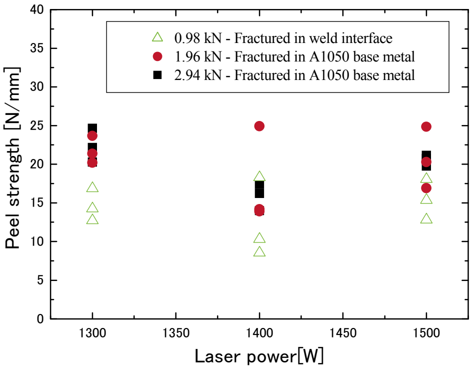


Fig. 7 Peel test results of Z12.

3.3 TEM observation and results of EDX analyses

In order to investigate the joining mechanism of the welded joints of GI steel and A1050, the TEM observation of the compound layer was carried out to examine the reason why the high joint strength was obtained even if the compound layer was thick. **Fig. 8** shows the results of the SIM image of GI steel/A1050 interface at low magnification. The whole intermetallic compound layer could not be observed by TEM because the compound layer was thick. Therefore, the TEM observation was carried out to investigate the interface between the compound and the respective parent metals. **Fig. 9** shows the TEM observation photographs at the A1050 side.

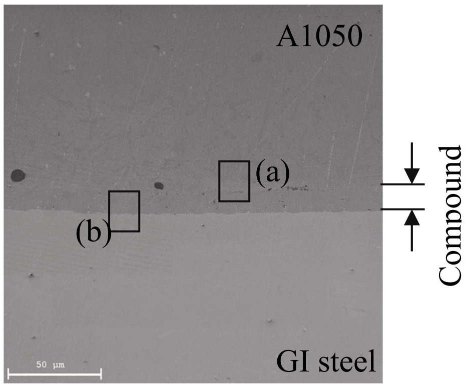


Fig. 8 SIM image of GI steel/A1050 interface at low magnification

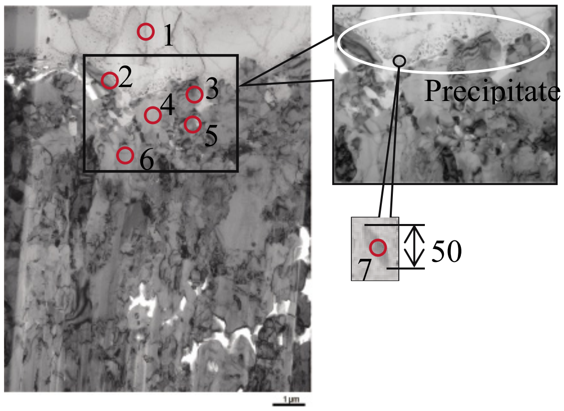


Fig. 9 TEM photos at higher magnification of Fig. 8 (a).

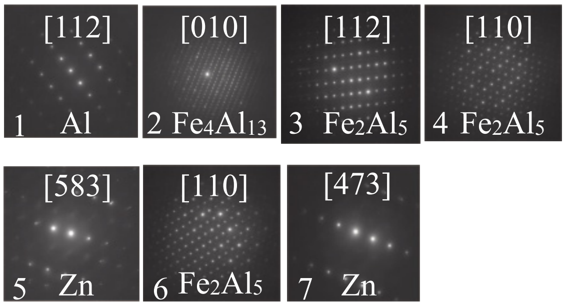
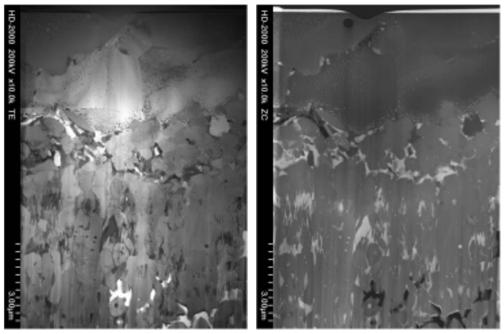


Fig. 10 Electron diffraction patterns from 7 points in Fig. 9.



BF-STEM image **DF-STEM image**

Fig. 11 BF image and DF image with STEM at A1050 side.

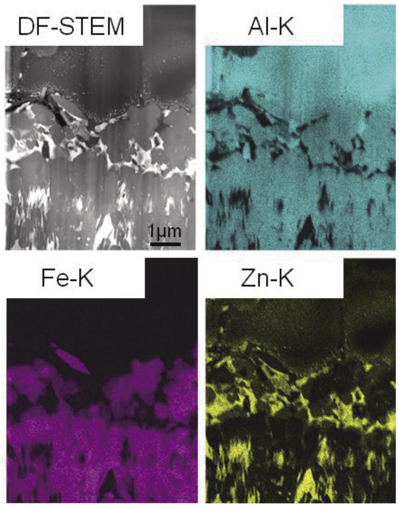


Fig. 12 DF image and EDX area analysis results in Fig. 11.

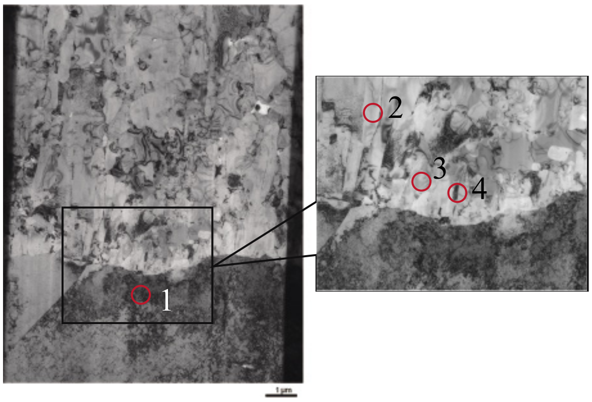


Fig. 13 TEM photo at higher magnification of Fig. 8 (b).

From the result of TEM observation at A1050 side in Fig. 9, many elliptical precipitates were observed in the aluminum phase. The sizes of elliptical precipitates were about 50 to 120 nm. These elliptical precipitates are supposed to be the Zn phase formed in the aluminum matrix. Moreover, many crystal grains were observed as the columnar phases. **Fig. 10** shows the electron diffraction patterns from 7 points in Fig. 9.

From the electron diffraction patterns, the points 3, 4 and 5 were identified as Fe_2Al_5, and the precipitates were identified as Zn. **Fig. 11** shows the bright-field (BF) image and the dark-field (DF) image with STEM. **Fig. 12** shows the EDX area analysis result in Fig. 11. From the observation results of BF image and DF image with STEM and the EDX area analysis result, the Zn phases were observed between the columnar phases. **Fig. 13** shows the result of the TEM observation photograph at the GA steel side. **Fig. 14** shows the electron diffraction patterns from 4 points in Fig. 13. From the electron diffraction patterns, the points 3 and 4 were identified as Fe_2Al_5 and Fe_4Al_{13}, and point 2 was identified as Zn. **Fig. 15** shows the BF image and DF image with STEM.

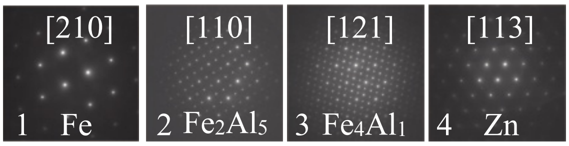
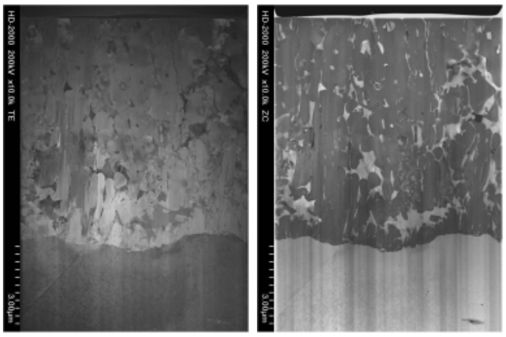


Fig. 14 Electron diffraction patterns from 4 points in Fig. 13.



BF-STEM image DF-STEM image

Fig. 15 BF image and DF image with STEM at GA steel side.

Fig. 16 shows the EDX area analysis result in Fig. 15. From the result of TEM observation at GI steel side, the mainly crystal phases were observed as the columnar phase, and the different crystal phases were observed between the columnar phases. From the result of EDX analysis, the crystal phases at the gap were thought to be Zn phases.

From these results, the joints consisted of the intermetallic compounds mainly, and the Zn phases were formed between the intermetallic compounds. The joining mechanism was different from the welding result of the GA steel and A1050. As the welding result of GA steel and A1050, the high joint strength was obtained by the formation of Al + Zn phase including finely dispersed intermetallic compounds.[6] In this research, even if the main constitution phases were the intermetallic compounds, the high joint strengths were obtained because the Zn phases were formed in the grain boundary of intermetallic compounds.

4. Conclusions

Dissimilar metals welding of GI steel and pure aluminum was performed using the laser pressure welding method by changing the laser power and the roller pressure. The mechanical properties of the welded joints were evaluated by the tensile shear test and the peel test. Moreover, the welded interfaces were observed by the TEM, and the crystal phases were identified by the electron diffraction method. The results obtained are summarized as follows:

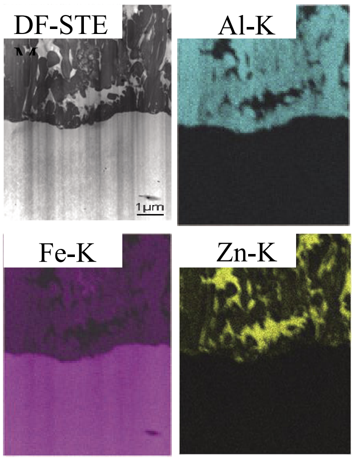


Fig. 16 DF image and EDX area analysis results in Fig. 15.

1. Dissimilar metals welding of GI steel and pure aluminum by laser pressure welding method was feasible in a wide range of welding conditions.
2. When the roller pressure was more than 1.96 kN under most welding conditions, the joint strength was so high that the specimens in the tensile shear and the peel tests fractured through the A1050 base metal.
3. Even if the main constitution phases were the intermetallic compounds, high joint strengths were obtained because the Zn phases formed in the grain boundary of intermetallic compounds.

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