

Laser Roll Welding of Dissimilar Metal Joint - SPCC Carbon Steel to Aluminum Alloy

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There is a subject to reduce the weight of car body by aluminum alloys replace steel as some structural body parts for improving fuel consumption and CO₂ generation. As one of the solutions, the multi material car body concept using aluminum alloys and high strength steels is discussed recently. Therefore, new welding processes by which these dissimilar metal joints can be joined in high reliability and productivity are demanded. Laser Roll Welding was developed for joining of dissimilar metals by M.Kutsuna and M.Rathod in 2002 at Nagoya University[1]. In the present work, Laser Roll Welding of SPCC carbon steel and aluminum alloy(A6022 and A6K21) was investigated, and the process parameters were studied to get reliable joint. Otherwise, the influences of process parameters and type of backing plate on the weldability, the formation of intermetallic compound layer and the mechanical properties have been investigated. When copper backing plate is used to get rapid cooling of welds, intermetallic compound layer of FeAl is formed, The failure of tensile-shear test specimen occurred in the base metal of the SPCC carbon eel. The tensile strength was 330MPa. The type of backing plate is very important factor to get ductile intermetallic compound like FeAl due to increasing the cooling rate of intermetallic compound.

Keywords: Laser roll welding, Dissimilar metal joint, Backing plate, Carbon steel, Aluminum alloy

1. Introduction

The car industry has subjects to improve fuel efficiency. One of the solutions is to reduce the weight of car body. To be replaced steel parts by aluminum alloys is very effective to achieve large weight reduction.

The technology for joining of steel to aluminum with high reliability and productivity is necessary to realize this "Multi Material body structure". However, it is not easy to join steel to aluminum by fusion welding. Fig.1 shows Fe-Al phase diagram.

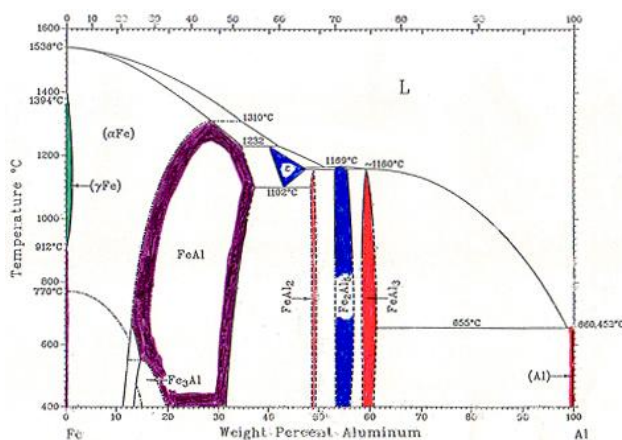


Fig.1 Fe-Al phase diagram [2].

The reason is attributed to the formation of intermetallic compounds such as FeAl₃ and Fe₂Al₅.

The intermetallic compounds presented on it are grouped as Fe-rich compounds (FeAl and Fe₃Al) and Al-rich compounds (FeAl₂, Fe₂Al₅ and FeAl₃). While Al-rich intermetallic compounds are brittle, iron-rich intermetallic compounds show slight ductility and high strength. Then, it is desirable that the brittle intermetallic compound could be controlled by Laser Roll Welding conditions..

In the present work, Laser Roll Welding of the SPCC zinc coated low carbon steel and the aluminum alloy was investigated, and the process parameters were studied. Otherwise, the influences of the process parameters and type of backing plate on the weldability, the formation of intermetallic compound layer and the mechanical properties of joints.

2. Experimental procedure

2.1 Materials

SPCC zinc coated steel sheet (GA) and aluminum alloy A6022/A6K21sheet were used for joining. The dimension of the steel sheet were 200 x 40 x 0.7 mm and 200 x 40 x 0.7mm and that of the 6000 series aluminum alloy was 200 x 40 x 1.2 mm. The steel sheet was polished by Emery paper #120 and coated by graphite spray before welding. The aluminum alloy was polished by Emery paper #400 and coated by brazing flux FL-7 before welding.

2.2 Laser Roll Welding Facility

A schematic diagram of Laser Roll Welding process is

shown in Fig.2. 3kW single mode fiber laser was used.

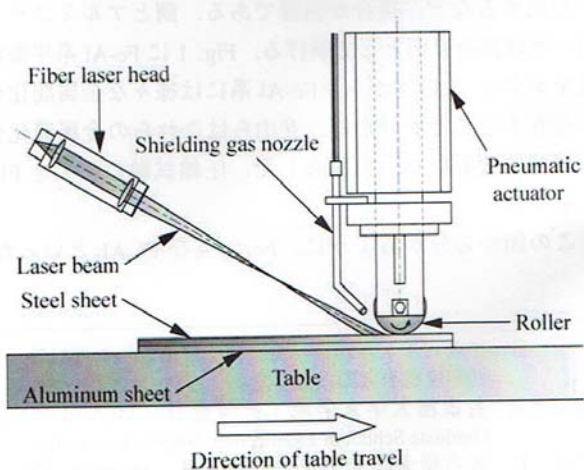


Fig.2 Schematic drawing of laser roll welding facility using a fiber laser

Laser Roll Welding was developed for joining of dissimilar metals by M.Kutsuna and M.Rathod in 2002 [3]. A stainless steel roller is used to make a contact of the steel sheet to aluminum alloy and to transfer the heat through the contact. The surface of steel sheet was heated up to 1300°C or 1400°C using a high power laser. It is desirable that thermal cycle for joining can be shortened by rapid heating of the laser and by rapid cooling using backing plate. The formation of the brittle intermetallic compound can be easily formed during slow heating and cooling. Therefore, It is important to control the thermal cycle during laser roll welding process. Fig.3 shows the laser roll welding facility used.

Laser Roll Welding Facility

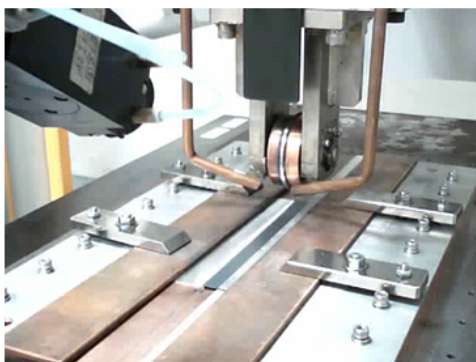


Fig.3 Laser roll welding facility used

2.3 Process parameters of Laser Roll Welding

The weld quality of laser roll welding depends on many process parameters are shown in Fig.4. In the present work, Travel speed, laser power, roll pressure, and type of backing plate are changed to get high quality joint as shown in Table 1. Travel speed was varied from 8 to 20 mm/s. Laser power was varied from 2100W to 2200W. Roll pressure (Loading force) was varied from 100N to 800N. 4 types of backing plate were used i.e. copper backing, aluminum alloy A6022 backing, SPCC steel

backing, and stainless steel AISI304 backing. The size of copper backing plate was 450x80x10mm as shown in Fig.5. The size of aluminum alloy backing plate was 200x40x1.2mm. That of AISI 304 stainless steel and SPCC steel backing was 300x40x1.0mm. The width of overlap was 7mm. Elliptical beam spot diameter was 7mm x 12mm. Argon gas shielding with 25 l/min flow rate was used for shielding of joint during process.

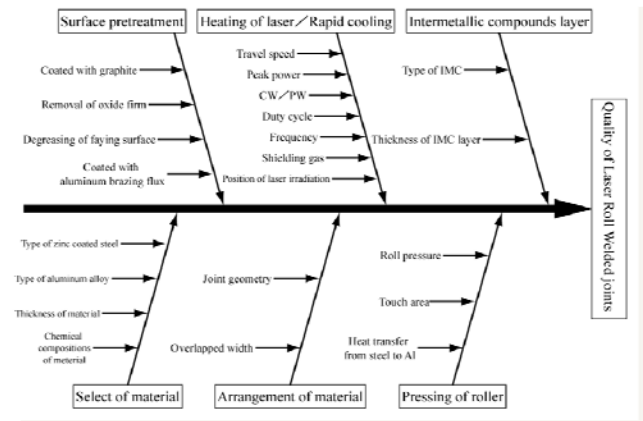


Fig. 4 Process parameters of laser roll welding

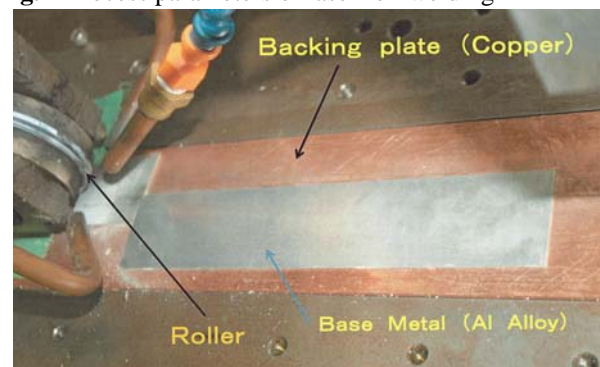


Fig.5 Copper backing plate below the base metal

Table 1 Laser roll welding conditions

Specimen No.	Laser Power (W)	Defocusing Distance D f (mm)	Travel speed mm/sec	Loading (N)	Shielding Gas and flow rate	Remarks
AT-1	2200	165	15	100	Ar 15+15	No Flux, Copper Backing
AT-2	2200	165	20	100	Ar 15+15	No Flux, Copper Backing
AT-8	2100	165	13	800	Ar 15+15	With Flux, Copper Backing
AT-9	2100	165	14	800	Ar 15+15	With Flux, Copper Backing
AT-10	2100	165	15	800	Ar 15+15	With Flux, Copper Backing
AT-11	2100	165	16	800	Ar 15+15	With Flux, Copper Backing
AT-12	2100	165	17	800	Ar 15+15	With Flux, Copper Backing
AT-25	2200	167	8	100	Ar 15+15	With Flux, Copper Backing
AT-26	2200	167	10	100	Ar 15+15	With Flux, Copper Backing
AT-27	2200	167	12	100	Ar 15+15	With Flux, Copper Backing
AT-28	2200	167	14	100	Ar 15+15	With Flux, Copper Backing
FA-2	2200	167	12	100	Ar 15+15	With Flux, Copper Backing
FA-4	2200	167	12	100	Ar 15+15	With Flux, Steel Backing
FA-5	2200	167	12	100	Ar 15+15	With Flux, SUS Backing
FA-6	2200	167	12	100	Ar 15+15	With Flux, Alumi. Backing
AK-25	2200	167	8	100	Ar 15+15	With Flux, Alumi. Backing
AK-26	2200	167	10	100	Ar 15+15	With Flux, Alumi. Backing
AK-27	2200	167	12	100	Ar 15+15	With Flux, Alumi. Backing

3. Experimental results and discussions

3.1 Bead appearance and cross-section of laser roll welded joints

Bead appearance of laser roll welded specimen AT-10 with travel speed of 15mm/s is shown in Fig.6. Aluminum alloy was melted and spread to the steel plate. No spatter

was observed. The cross-sections of laser roll welded specimen FA-2(copper backing) and FA-6(aluminum backing) are shown in Fig.7.

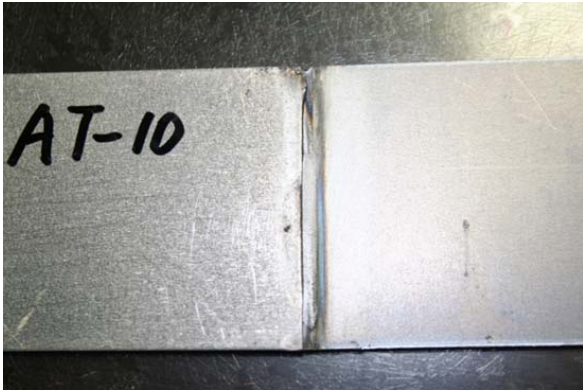
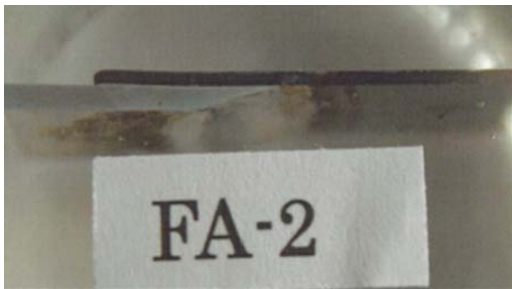
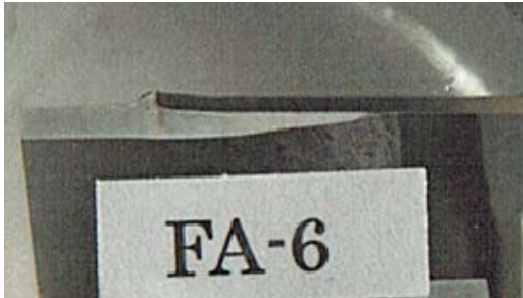


Fig.6 Bead appearance of laser roll welded specimen AT-10



(a) Specimen FA-2(Copper backing)



(b) Specimen FA-6 (Aluminum backing)

Fig.7 Cross-sections of laser roll welded specimen FA-2 (copper backing) and FA-6(aluminum backing)

This figure shows partial melting of aluminum alloy and spreading of molten metal on steel sheet for joining. As a result, The overlapping width of joint become about 10mm .

3.2 Effect of backing plate on intermetallic compound at joint interface

Existence of intermetallic compound layer was confirmed at the joint interface between GA steel and A6022. Interface microstructures of laser roll welded joint FA-2 (Location 2) with copper backing plate is shown in Figs.8. Two interlayers are shown at the joint interface. One of them includes Kirkendall Voids near the steel side. Another layer near aluminum alloy side has no such a void. Because, Mutual Diffusion coefficient of Fe into Al is higher than that of Al into Fe at elevated temperature.

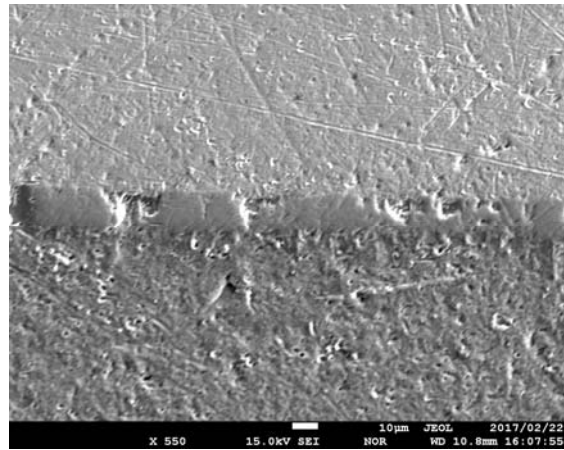


Fig.8 Microstructure of joint FA-6 at the interface (Location 2)

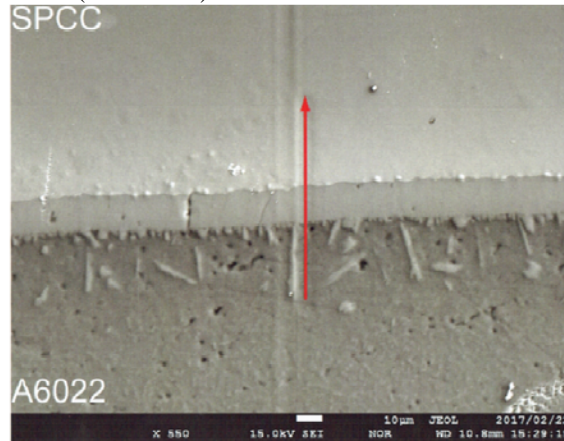


Fig.9 Microstructure of joint FA-2 at the interface (Location 3)

Fig.9 shows the microstructure of joint FA-2 (Location 3) at the interface. One interlayer is shown at the joint interface. Few of Kirkendall Voids is observed. Because of rapid cooling by copper backing plate. ,

3.3 Electron-probe microanalysis (EPMA)

As the optical microstructure is not identified the interface layer, EPMA line analysis was performed. Distribution of iron and aluminum across the interlayer were detected to identify intermetallic compounds. The results of EPMA for FA-2 joint (Location 2) is shown in Fig.10. The analysis line is shown in Fig.9.

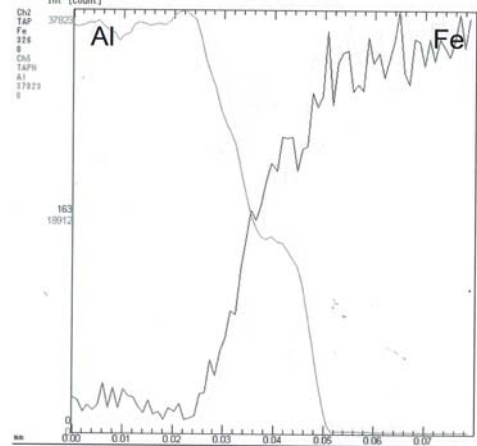


Fig.10 Result of EPMA for FA-2 joint (Location2) Variation in composition of the intermetallic compound

layer is observed as stepped lines. Intermetallic compound layers are indicated by the step. In the phase diagram of Fe-Al, 5 types of intermetallic compound are recognized.

From the 4 position of steps, it is suggested that 4 types of intermetallic compound (FeAl, FeAl₂, Fe₂Al₅, FeAl₃) are formed. The results of EPMA for FA-2 joint (location 3) is shown in Figs.11 The analysis line is shown in Fig.10.

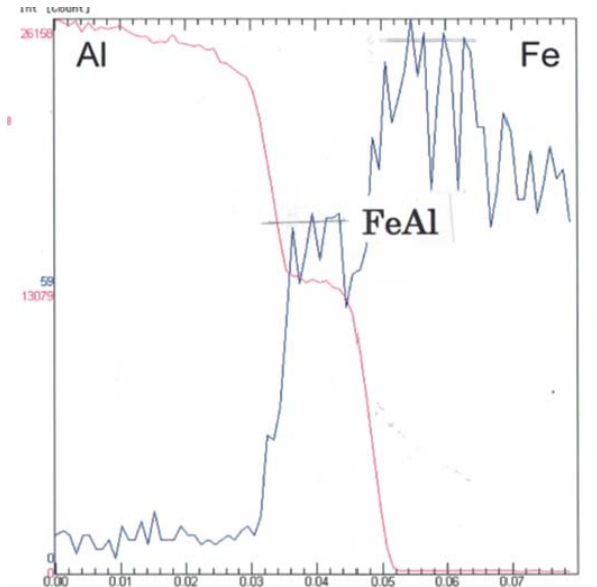


Fig.11 Result of EPMA for FA-2 joint (Location 3)

From the position of main step, it is suggested that intermetallic compound of main interlayer is ductile FeAl compound.

3.4 Tensile shear test

Tensile shear test was done to investigate the influence of welding conditions such as flux, thickness of steel, travel speed and backing plate on the joint performance. Effect of backing plate on tensile shear strength is remarkable as shown in Table 2.

Table 2 Result of tensile test of LRW joints

Specimen No	Output power (W)	Travel speed (mm/s)	Loading pressure (N)	Shielding Gas (Ar) (L/min) ^①	Tensile strength (MPa)	Type of Backing
AT-25	2200	8	100	15+15	169	Copper backing
AT-26	2200	10	100	15+15	153	Copper backing
AT-27	2200	12	100	15+15	119	Copper backing
AT-28	2200	14	100	15+15	179	Copper backing
AK-25	2200	8	100	15+15	102	Aluminum backing
AK-26	2200	10	100	15+15	168	Aluminum backing
AK-27	2200	12	100	15+15	215	Aluminum backing
FA-2	2200	12	100	15+15	330	Copper backing
FA-4	2200	12	100	15+15	126	Steel backing
FA-5	2200	12	100	15+15	153	Stainless steel backing
FA-6	2200	12	100	15+15	294	Aluminum backing

Note ①: Front gas shielding and side gas shielding

Brazing flux is required to get sound welded joint.

Fig.12 shows the tensile test specimen of joint FA-2 after test. The specimen was broken at the base metal of SPCC steel of 0.7mm in thickness.

The relationship between tensile strength of LRW joint and thermal conductivity of backing plate is shown in Fig.13. It is founded that copper backing plate is good backing plate to get enough strength.



Fig.12 Tensile test specimen of joint FA-2 after test

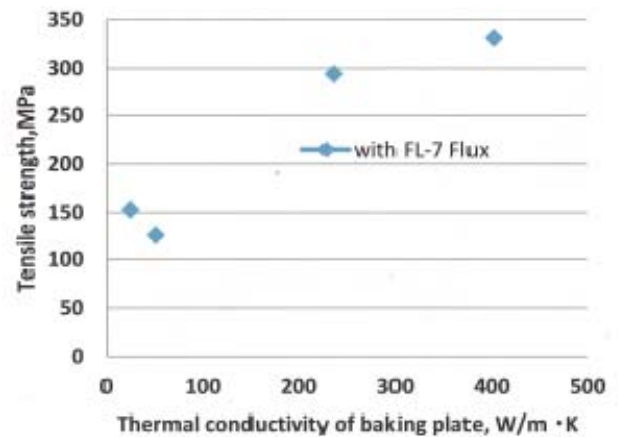


Fig.13 Relation between tensile strength of LRW joint and thermal conductivity of backing plate

4. Conclusions

The present study is focused on joining a dissimilar metal combination of zinc coated steel SPCC and A6022 and A6K21 aluminum alloys. The following conclusions can be drawn.

- 1) Brazing flux is required to get enough strength in laser roll welding.
- 2) It is suggested that intermetallic compound at the joint interlayer is ductile FeAl in copper backing process at the travel speed of 12mm/s.
- 3) When intermetallic compound layer has FeAl compound, the laser roll welded joint can be broken at the coated steel in tensile shear test.

References

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