CORROSION SCIENCE AND TECHNOLOGY, Vol.5, No.6(2006), pp.196~200

Corrosion Behavior of Arc Weld and Friction Stir Weld in Al 6061-T6 Alloys

Byoung-Hyun Yoon, Heung-Ju Kim, Woong-Seong Chang, and † Young-Gak Kweon

Welding Research Center, Research Institute of Industrial Science and Technology
Pohang 790-600, South Korea

For the evaluation of corrosion resistance of Al 6061-T6 alloy, Tafel method and immersion test was performed with Friction Stir Weld(FSW) and Gas Metal Arc Weld(GMAW). The Tafel and immersion test results indicated that GMA weld was severely attacked compared with those of friction stir weld. It may be mainly due to the galvanic corrosion mechanism act on the GMA weld.

Keywords *: corrosion resistance, aluminum alloy, friction stir weld, gas metal arc weld*

1. Introduction

Recently growing demand for environmental protection and energy conservation are the rapid developments of technologies to lighten transportation vehicles such as automobiles, airplanes, train cars, and ships; hence the increasingly widespread use of lightweight alloys such as Al and Mg alloys.

The assembly of various machinery and structures involves welding processes. Note, however, that the welding of Al alloys poses many problems that need to be addressed, e.g., technological, economical, and environmental issues. As a new technological solution to problems occurring in fusion-welding of Al alloys, the technology of friction stir welding (FSW), solid-state welding process, has been widely used in various industrial field particularly lightweight transportation vehicles.

For FSW technology, the results of several studies conducted in advanced countries regarding the relevant welding factors, structures of machinery and tools, and other application technologies have been shown at international meetings for the last 10 years. Industrial interest in the application of this technology has also been increasing gradually. However, relatively few investigations have been carried out on corrosion properties of friction stir weld of Al alloys.[1),2)] Therefore, this study attempted to evaluate the corrosion characteristics of FS-welded parts and compared them with those of GMA-welded parts.

† Corresponding author: ygkweon@rist.re.kr

2. Experimental procedures

The aluminum alloy used in this experiment was Al 6061-T6 alloy, a representative aluminum alloy of the precipitation-hardening type. Table 1 and 2 were shown the chemical compositions and mechanical characteristics of Al6061-T6 alloy.

Table 1. Chemical compositions of Al 6061-T6 alloy. (wt%)

Mg	Si	Sn	Mn	Fe	Cu	Cr	Ti	Al
1.06	0.65	0.02	0.04	0.37	0.25	0.2	0.01	Bal.

Table 2. Mechanical properties of Al 6061-T6 alloy.

Yield strength (Kg/mm^2)	Tensile strength (Kg/mm^2)	Elongation (%in 5cm)	Hardness (BHN)
28	32	12	95

The Al 6061-T6 alloy was welded by FSW and GMAW. Used welding conditions are showed at Table 3. In the GMAW, two types of welding materials are used.

The welded specimens were metallographically prepared by sectioning, mounting in epoxy, grinding and polishing through 0.05 micron alumina. Microstructural details were revealed by etching with fluoric acid. Characterization methods included light and scanning electron microscopy and energy-dispersive x-ray analysis.

Table 3. Welding conditions of used Al 6061-T6 alloy.

		Rotation Speed (rpm)	Welding Speed (mm/min)		
FSW		1000	200		
	Welding Materials	Current (A)	Voltage (V)	Welding Speed (cm/min)	Ar Gas (l /min)
GMAW	4043	170	20	40	20
	5356	160	20	40	20

In this study, a widely used corrosion evaluation method, electrochemical polarization, was selected since it required less experiment time and it could also be conducted in a non-destructive manner.

The equipment used for the polarization experiment were EG&G's Model 273A Potentiostatt and PC (personal computer). M352W Corrosion software was also used to carry out the experiments on the polarization characteristics, SCE, as the reference electrode. On the other hand, to determine the corrosion characteristics in corrosion environments, immersion tests were carried out in accordance with ASTM G 110. In order to confirm the corrosion product of each specimens were analyzed by X-ray diffraction method.

Table 4. Experimental conditions of the polarization test.

Initial potential	-0.25V
Final potential	0.25V
Scan rate	0.5mV/s
Step time	1S
Step Increasing	0.5mV
Electro Area	$1cm^2$

Table 5. Experimental conditions of immersion test.

Specimen	BM, FSW, GMAW4, GMAW5
Size(mm)	30 × 10 × 4
Time(hours)	24, 48, 120
Etching cleaner (1min at 95℃)	945㎖ reagent water +50㎖ nitric acid + 5㎖ hydrofluoric acid
Test solution	57g sodium chloride +10㎖ hydrogen peroxide + 1.0 l reagent water

Table 4 and 5 were shown the conditions for the polarization experiments and immersion tests, respectively.

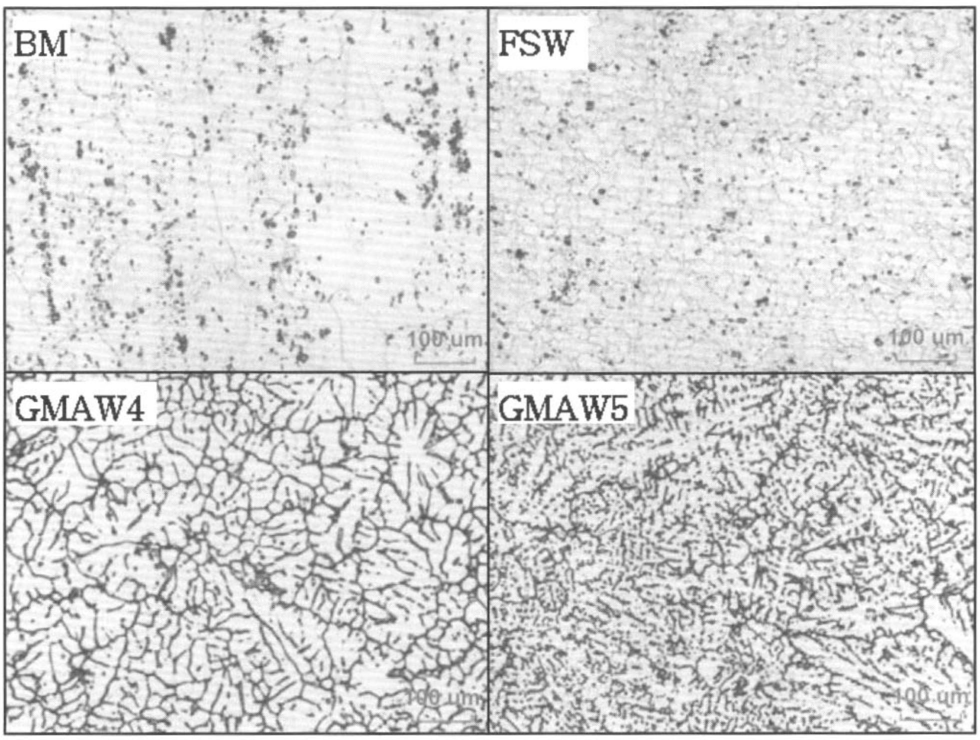

Fig. 1. Microstructure of Al 6061 alloy weld metals.

3. Results and discussion

3.1 Microstructure characterization

Typical microstructures of the weldment are presented in Fig. 1. These Optical Microscopy photographs were taken in the weld metal. In the FSW, stir zone is revealed fine grained microstructure. For the GMAW, weld metal is revealed dendrite microstructure. The microstructure of GMAW5 specimen is similar to GMAW4 specimen but for the volume fraction of precipitates is much larger (Fig.1).

3.2 Tafel test

Fig. 2 shows the polarization curves of 6061 Aluminum alloys with various welding method. The lowest electric current density and corrosion potential were measured in FSW, with corrosion potential and electric current density increasing in BM followed by GMAW. In other words, FSW was the least corroded. Fig. 3 shows the corrosion rate with various welding condition by Icorr and Ecorr as measured in polarization curves. The corrosion rate in the FSW was lower than the GMAW4, 5 and BM. GMAW5 specimens was revealed highest corrosion rate.

3.3 Immersion test

The immersion test for each specimens were conducted on the condition of 24h, 48h, and 120h. Fig. 4 shows the shapes of the specimen following the corrosion. Based on the visual inspection using the naked eye, base metal(BM) was found to have shown lowest corrosion, and FSW

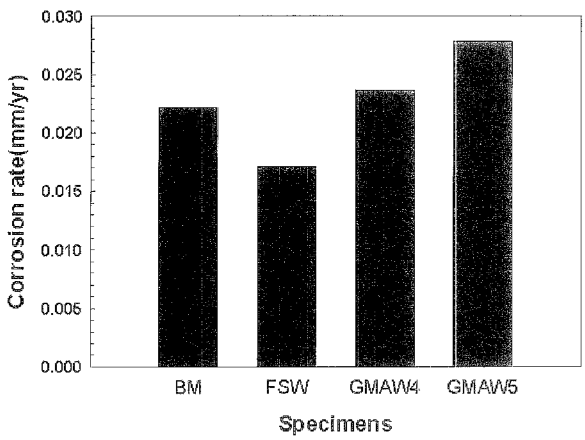

Fig. 2. Tafel polarization curves for Al 6061 alloy with various welds at 3.5% NaCl solution.

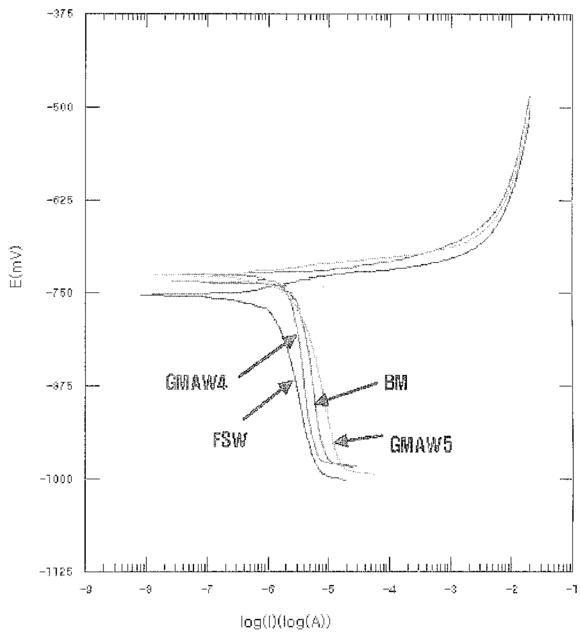

Fig. 3. Comparison of corrosion Rate of each specimens.

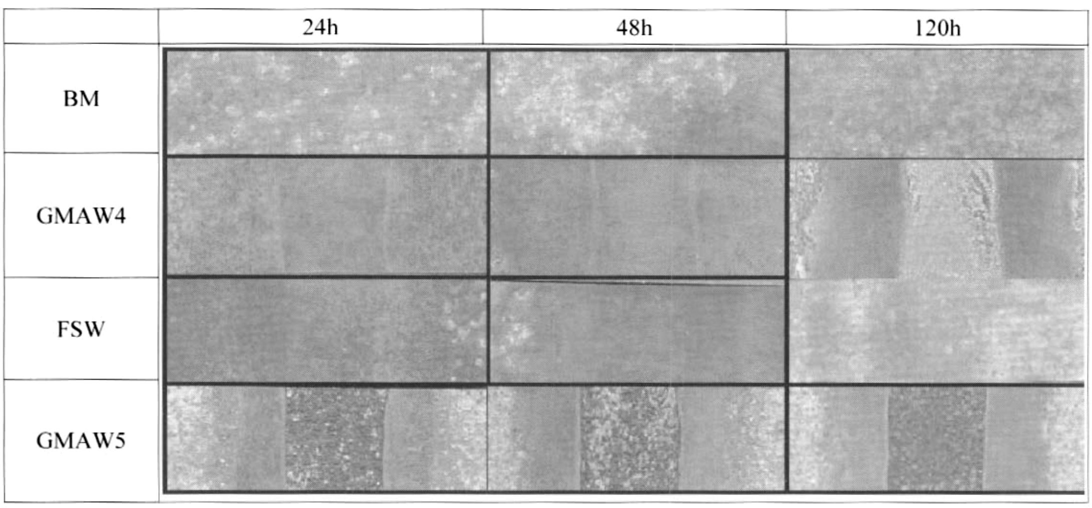

Fig. 4. Corrosion appearances after immersion test.

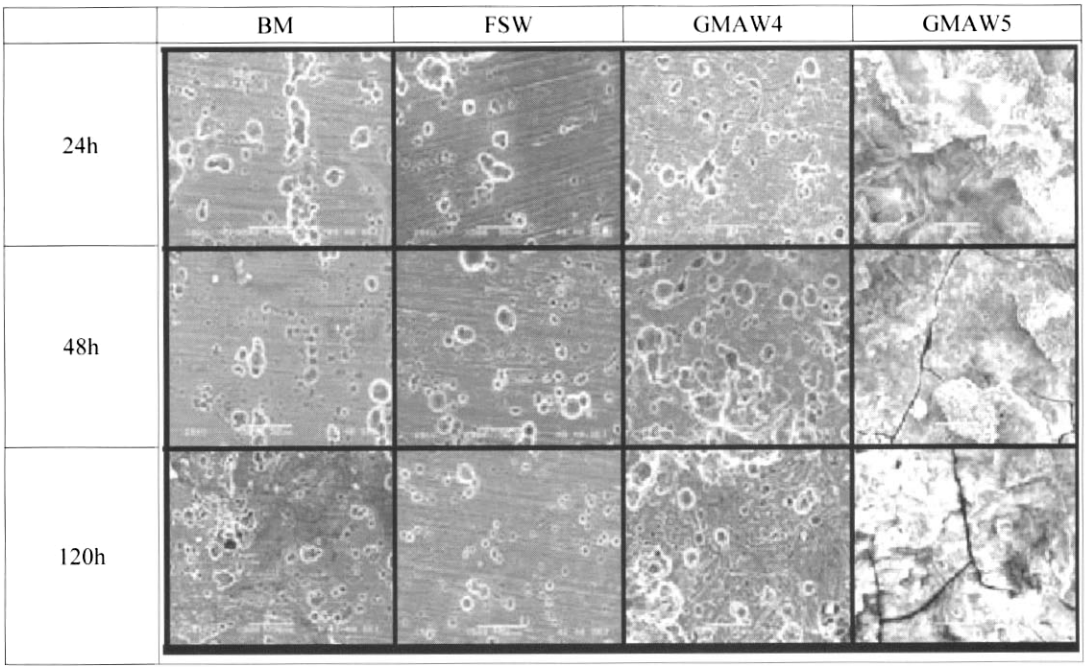

Fig. 5. SEM photos of each specimens after immersion test.

specimens was similar to base metal(BM). On the other hand, the GMAW5 specimen with using 5356 filler material was severely corroded. The GMAW5 specimen was more corroded than that using 4043 filler material.

After immersion test, SEM observation of immersion tested specimens were also conducted to check corrosion more accurately. Base metal and FSW specimens were found to be the less corroded than other specimens. GMAW specimens were more corroded than FSW specimen. In particular, the weld metal of GMAW using 5356 filler material(GMAW5) was severely corroded, suggesting that extensive pitting corrosions and cracking occurred after 24h.

The alloying elements of the corroded surfaces were also analyzed by EDS. Fig. 6 shows the results of SEM EDAX analysis of each specimens. Results showed some differences in the alloying elements of the corroded specimen particularly a striking difference in the Al and O contents. Aluminum and oxygen contents of each specimens were changed with increasing immersion time. Aluminum content of each specimens were decreased with increasing immersion time and oxygen content of each specimens were increased with increasing immersion time.

Note that the reaction between aluminum and oxygen can be expected to cause corrosion, with increasing oxygen content accelerating the corrosion process. The GMA welded specimen with 5356 filler material has high oxygen content without immersion time, whereas the other specimens has low oxygen.

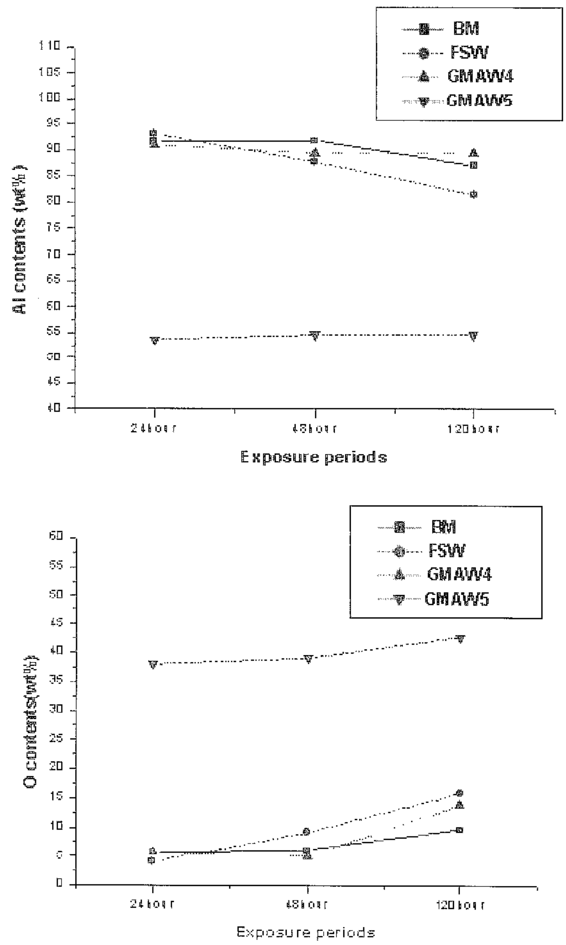

Fig. 6. Variation of Al and O contents according to exposure periods.

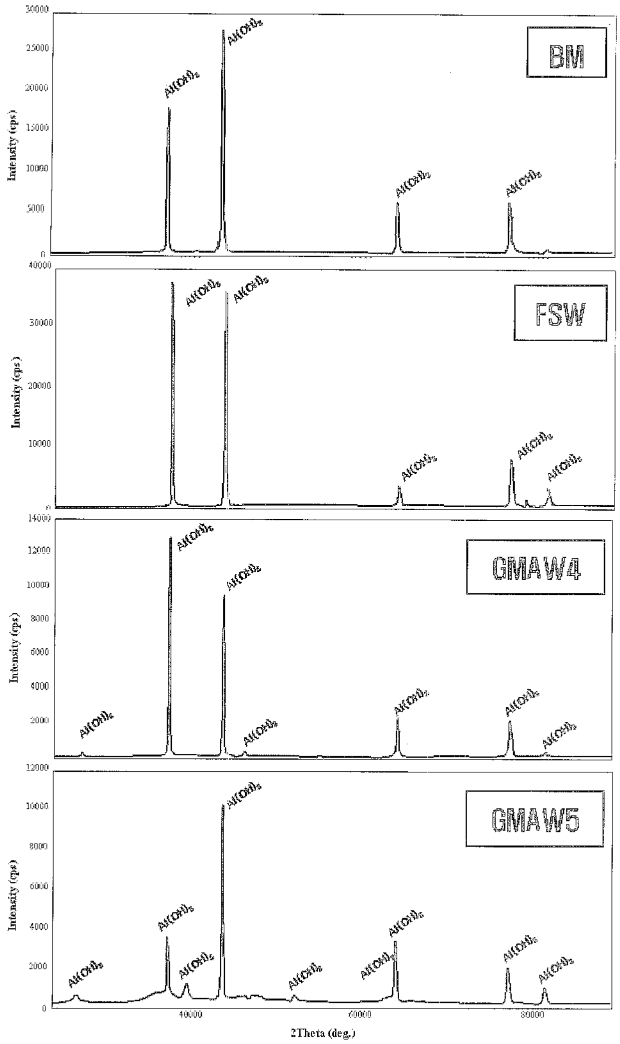

Fig. 7. XRD analysis of each specimen after immersion test.

Fig. 7 shows the XRD analysis results that the generated corrosion products on each specimen were $Al(OH)_3$. All the specimens form $Al(OH)_3$ according to the following order:

$$2Al + 3NaCl \rightarrow 2AlCl_3 + 3H_2\uparrow \quad (1)$$

$$2Al + 6H_2O \rightarrow 2Al(OH)_3 + 3H_2\uparrow \quad (2)$$

$$2AlCl_3 + 6H_2O \rightarrow 2Al(OH)_3 + 3H_2\uparrow + Cl_2\uparrow \quad (3)$$

$$Al(OH)_3 \rightarrow AlOOH + H_2O \quad (4)$$

Al and NaCl react with each other and form $AlCl_3$ (1), with $AlCl_3$ reacting again with H_2O to produce $Al(OH)_3$ oxide layers (3). Al also reacts with H_2O to produce $Al(OH)_3$ oxide layers (2). $Al(OH)_3$ oxide layers are destroyed after a certain time (4). The destruction process occurs in the form of pitting corrosion and cracks.

4. Conclusions

To evaluate the corrosion characteristics in the arc welded parts using different filler material, FSW and parental metal, Tafel and immersion tests were conducted. The following results were derived:

1) The results of Tafel tests showed GMA (WM) exhibiting the highest corrosion rate, followed by BM and FSW (SZ).

2) The results of the immersion tests showed that GMA welding using 5356 filler material enabled the most active corrosion process. Friction stir welded aluminum alloys revealed the best corrosion characteristics.

3) The generated corrosion products were confirmed to be $Al(OH)_3$.

References

1. F. Hannour, A. J. Davenport, and M. Strangwood, "Corrosion of Friction Stir Welds in High Strength Aluminum Alloys", *2nd International Symposium on Friction Stir Welding, 26-28 June 2000*, Gothenburg, Sweden (2000).
2. A. J. Leonard, "Corrosion resistance of Friction Stir Welds in Aluminum Alloys 2024A-T651 and 7075-T651", *3rd International Symposium on Friction Stir Welding* (2004).