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Effect of Heat Treatment on Corrosion behavior for Friction Stir Welding of aluminum alloys AA 2024- AA 6061

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Abstract

This work aims to study the effect of aging heat treatment of friction stir welding of aluminum alloys AA 2024- AA 6061 on corrosion behavior. The dimensions of aluminum alloys plates which used are 85mm, 150 mm and 6mm as width, length and thickness respectively. The welding process was done using a milling machine and welding tool with cylindrical shape (18mm and 6mm of shoulder and pin diameters respectively, with 5.8mm as a pin length). The welding process conditions were 1040 rpm and 30 mm/min as tool rotation speed and welding speed respectively. After the welding process, heat treatment process was conducted. The samples were heated to a temperature of 520 °C for 30 minutes followed by a cooling process in water, then, it has been aging at a temperature of 210 ^{0}C for 4 hours. The microstructures of the samples of the base alloys and friction stir welding are examined by using optical microscopy and the corrosion test done by using a WENKING Mlab multi channels potentiostat and SCI-Mlab corrosion measuring system to plotted Tafel polarization curves in 3.5% NaCl solution. The results shown that the microstructure of the FSW sample after heat treatment has a finer uniform distribution precipitates and has high corrosion resistance.
Keywords: Aluminum alloys, Heat treatment, Friction stir welding, Corrosion.

1. Introduction

Aluminum alloys are considered the task of alloys in the industry because of the good properties. Aluminum alloys used in the aerospace, automotive and many other applications because of light weight, corrosion resistance and high strength / weight ratio [1, 2]. On the other hand, the aluminum alloys are non-weldable by traditional welding methods (fusion welding) because they lead to get porosity and low mechanical properties [3].

Friction stir welding (FSW) is a joining process invented in 1991 by The Welding Institute (TWI) [4]. This Joining process is solid state welding. This type of welding is suitable for welding the metals and alloys that are difficult to weld by fusion welding methods. FSW is welding-friendly environment, where in this welding process, not using any gas during welding, on the other hand, it is characterized by clean, good mechanical properties and good dimensional control [5]. It is used in welding similar and dissimilar metals such as aluminum, copper, steel and magnesium [6].

In Friction Stir Welding using cylindrical tool, consists of two parts, pin and shoulder, the best ratio between pin to shoulder diameters is 1/3[7]. Pin diameter mostly be equal to the thickness of the metal to be welded and the length less in a several parts of a millimeter from the thickness of the metal [8].

The welding process occurs as a resulting friction and stirring. The rotation of the welding tool and friction it with the metal leads to the generation the heat, in the same time, the rotation lead to mechanical stirring of the metal to be welded [9]. This heat and mixing of the metal leads to the formation different zones, varies in microstructure and mechanical properties from one zone to another. In this type of welding, four zones consisting after welding, namely, (from welding center to the outside) SZ (Stir Zone), TMAZ (Thermo Mechanical Affected Zone), HAZ (Heat Affected Zone) and BM (Base Metal) [10]. Gharavi et al. [11] studied the corrosion behavior of friction stir welding joints of aluminum alloy (AA6061-T6) in 3.5% NaCl solution (pH=5.5). They are found that the intermetallic precipitates are divided into two types, Si-rich precipitates and Fe-rich precipitates with different in color and morphology. Also, the results show that the precipitates play an important role in the corrosion behavior. The welding zones (Stir zone and Heat affected zone) are poorer than parent alloy and the parent alloy is nobler than welding zones.

Muna K. et al. [12] evaluated the effect of aging treatment on corrosion resistance of friction stir welding of AA2024 aluminum alloy. The aluminum alloy welded and treated (precipitation heat treatment) and tested for corrosion resistance by using 3.5% NaCl as a corrosion solution. The results show that the corrosion resistance of AA2024 alloy decrease after welding process and increases after an aging treatment. Also, the results showed that the base alloy have better corrosion resistance than it (base alloy) after welding and heat treatment.

Muruganandam D.et al. [13] studied the corrosion on AA 6061 and AA7075 joints by friction stir welding in NaCl solution. The results showed that welded AA6061 to AA7075 occurred to pitting corrosion in stir zone and alloy AA6061 was characterized by being more resistant to this type of corrosion.

A. J. Davenport et al. [14] evaluated the corrosion behavior of friction stir welding joints of AA2024 and AA7010 aluminum alloys in 0.1 M NaCl solution. They

show that the welding zones difference in grain size, and the stir zone contain finer grains compared with other zones. Also noted that the corrosion driven by the microstructure that formed during welding process. Intergranular corrosion occurs in heat affected zone and stir zone.
In this work, the effect of friction stir welding process and aging heat treatment on corrosion behavior in 3.5% NaCl was study. Also to determine the corrosion parameters (Ecorr) and (Icorr).

2. Experimental Work.

1.1. Materials

In this study, thick plates (6mm) of aluminum alloys are used. Al-Cu (AA2024-T3) and Al-Si-Mg (AA6061-T651) and these alloys in natural aging state. The dimensions of the two plates which are used in welding process are 85mm and 150 mm as width and length respectively. Table 1 represents the chemical composition of these alloys. The chemical analysis was done at the state company for inspection & engineering rehabilitation, using Thermo ARL 3460, Optical Emission Spectrometer.

Table 1 chemical composition of aluminum alloys.

Element Wt.	2024 alloy	6061 alloy
Si	0.110	0.752
Fe	0.313	0.599
Cu	4.5	0.372
Mn	0.566	0.090
Mg	1.23	1.08
Cr	0.026	0.239
Zn	0.147	0.071
Ti	0.018	0.009
Al	Bal	Bal

2.2. Welding process

The welding process done by using a milling machine and welding tool with cylindrical shape. The tool was manufactured from stainless steel (T31501, O1), (18mm and 6mm for shoulder and pin diameters respectively, with 5.8mm as a pin length). The welding process conditions are 1040 rpm and 30 mm/min as tool rotation speed and welding speed respectively. Figures (1 and 2) represent the welding tool and welding process respectively.

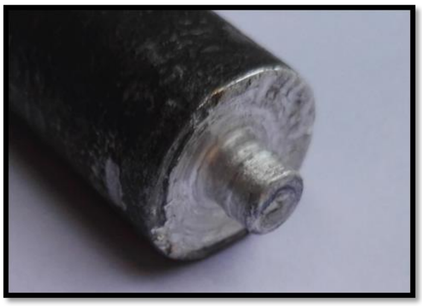


Fig.1 FSW tool.

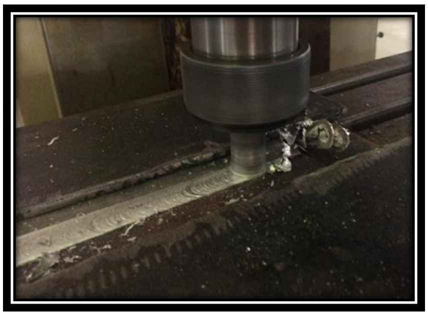


Fig.2 welding process

2.3 precipitation Heat treatment process

After a welding process, precipitation heat treatment process was conducted in electric furnace. The samples were heated to a temperature of 520 °C for 30 minutes followed by a cooling process in water, then, it has been aging at a temperature of 210 ^{0}C for 4 hours.

2.4 Microstructure examinations.

The microstructure testing by using optical microscope. The samples made from a cross section of the friction stir welding. Three groups of samples at conditions (bases alloys, as welded and after aging treatment). The samples were cutting and wet grinding by using emery papers of SiC (320, 500,800 and 1000 grits) with water. The samples after grinding was polishing by using diamond paste (1 µm as grain size) with polishing cloth and lubricant. Etching process was done after polishing by using Keller's reagent (2.5ml HNO_3, 1.5ml HCl, 1ml HF and 95ml H_2O). The microstructure of the samples was examined by Nikon (1200F) optical microscope with a Nikon camera.

2.5 Corrosion Tests

The corrosion behavior of the FSW samples are examined by a WENKING Mlab multi channels potentiostat and SCI-Mlab corrosion measuring system as show in figure (6) to plotted Tafel polarization curves in alloys in 3.5% NaCl solution .The samples for corrosion measurements were cutting of (15 * 15 * 6) mm, the samples were cut perpendicular to the welding line to take them from thermo mechanical affected zone and stir zone, were prepared using SiC emery paper up to 1200 grit and then polished using a diamond paste and then washed with water, finally, washed with alcohol and dried.

The corrosion rates for FSW joint measured by Polarization resistance tests. (-100 to +100) mV relative to (OCP) as a sweep. The curve of the voltage in this range of current is almost nearly linear. Estimate the polarization resistance done by fitting linear data of standard model to calculate (Icorr) corrosion current density and corrosion rate.

3. Results and Discussion.

3.1. Microstructure results

The microstructure of the friction stir welding joints is separated to four zones ; base metal, heat affected zone, thermo mechanical affected zone and stir zone, Figure (3) shows the microstructure of the base alloy (AA2024 and AA6061) where the Figure (4) shows the microstructure of the different zones of FSW joint (as weld). Figure (5) shows the microstructure of the different zones of FSW joint (after aging treatment 4 hours).

The microstructure of 2024 alloy (figure (3-a)) contains coarse precipitation phases in α-Al matrix where the microstructure of the 6061 alloy as show in (figure (3-b)) contains coarse precipitates and eutectic phases in α-Al matrix. It was shown in figure (4) that the microstructure of welded samples contains different sizes of grains and precipitation phases, in stir zone, the grains and precipitation are finer than base alloy (figure (4-d)). The grains in thermo mechanical affected zone are growth due to plastic deformation as show in figure (4-c & 4-e), While the grains in heat affected zone are coarse due to heat that generated from welding. The microstructures of joint after quenching, aging treatment (4) hours have a finer uniform distribution precipitates as show in figure (5). Figure (5-d) represented that the precipitates in stir zone are finer other zones, this due to plastic deformation.

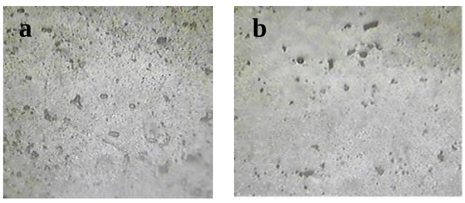
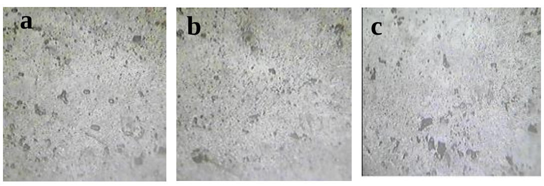


Fig.3 microstructures of the base alloys a) AA2024 alloy, b) AA6061,250X



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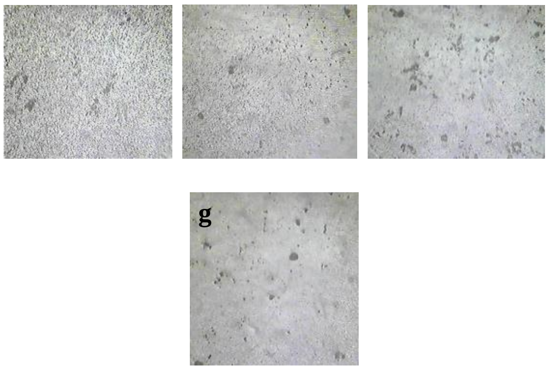

Fig.4 microstructures of welded joint : a) base alloy 2024, b) HAZ 2024, c) TMAZ 2024,d) SZ, e) TMAZ 6061, f) HAZ 6061, g) BM 6061. 250 X.

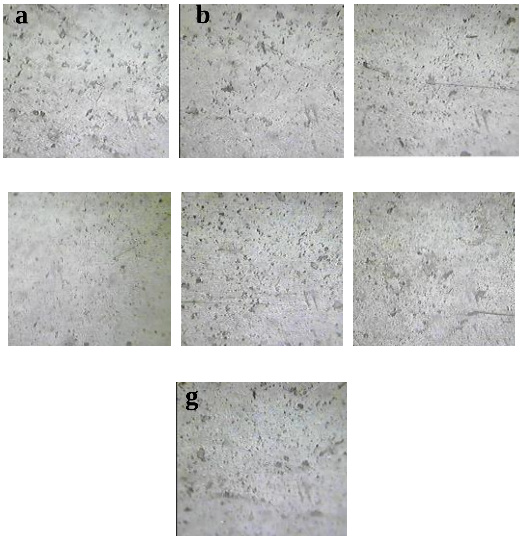

Fig.5 microstructures of welded joint after 4 hours aging : a) base alloy 2024, b) HAZ 2024, c) TMAZ 2024,d) SZ, e) TMAZ 6061, f) HAZ 6061, g) BM 6061. 250 X.

3.2. Corrosion Results

When the Aluminum alloys exposed to water, passive oxide film formd on the surface, and these oxide film led to increase the corrosion resistance. On the other hand the corrosion rate increased due to the presence of chloride ions in solution. The concentration of Cl- effects on the severity and depth of pitting corrosion of aluminum alloys. With increasing the concentration, the corrosion becomes more severe. Other factors affecting on the corrosion rate of the aluminum alloy is heterogeneity of the microstructure. The uniform of the microstructure improve the corrosion resistance[15].

Table 1 corrosion tests results of the base alloys and FSW joints.

Sample	Heat treatment status	Ecorr (mV)	Icorr ($\mu A/cm^2$)
Base alloy 2024	As received	-629.7	75.19
Base alloy 6061	As received	-635.2	70.30
Weld joint	AS weld	-570	13.09
Weld joint	Solution heat treated 520 °C +aging at 210 ^{0}C for 4hrs.	-628.5	12.32

Figures (6) show the polarization curves of the AA2024 & AA6061 alloys (base alloy), figure (7) show the polarization curves of the FSW sample before and after age heat treatment respectively in 3.5% NaCl at 30ºC.

The corrosion rate different from the base alloys to FSW joint. Table (2) shows the corrosion test results of the base alloys and the FSW joints before and after heat treatment. The base alloys have lower corrosion resistance (high Icorr (75.19 & 70.30) $\mu A/cm^2$), whereas the FSW samples after heat treatment have high corrosion resistance (lower Icorr (13.09 &12.32) $\mu A/cm^2$). When compare the microstructures of the base alloys and FSW joints before aging treatment (figures (3&4)), all samples have coarser precipitates except the microstructure of the stir zone. The microstructure of the FSW sample after precipitation heat treatment has a finer uniform distribution precipitates as shown in figure (5). EL-Bedawy noted in Al-Si-Mg aluminum alloy, that the precipitates phases are more noble than the matrix [16]. Muna K. et al., also noted that the precipitates in 2024 Aluminum alloy are more noble than the surrounding solid solution[12]. The FSW samples after aging treatment have higher corrosion resistance than FSW before heat treatment. Generally, the corrosion rate of the FSW samples before and after aging treatment have corrosion resistance less than the base alloys (as reserved). The precipitates in the base alloy are coarse than the precipitates after aging treatment and have nonuniform microstructure as shown in figure (3&4) and figure (4-a & g), this leads to decrease corrosion resistance[16].

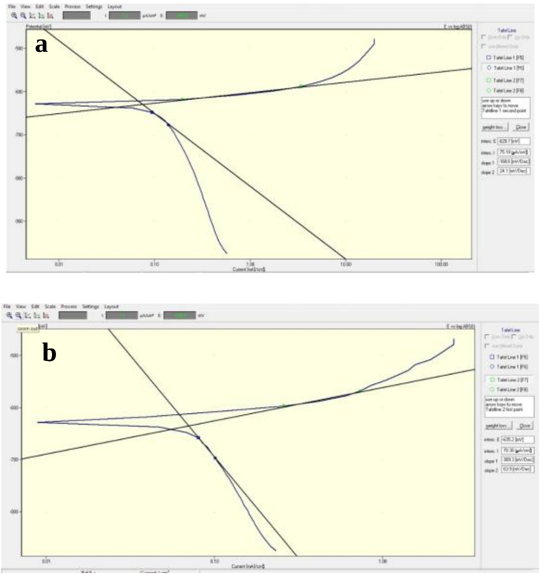

Fig.6 polarization curves: a) 2024, b) 6061 base alloys in 3.5% NaCl solution at temperature of 30ºC.

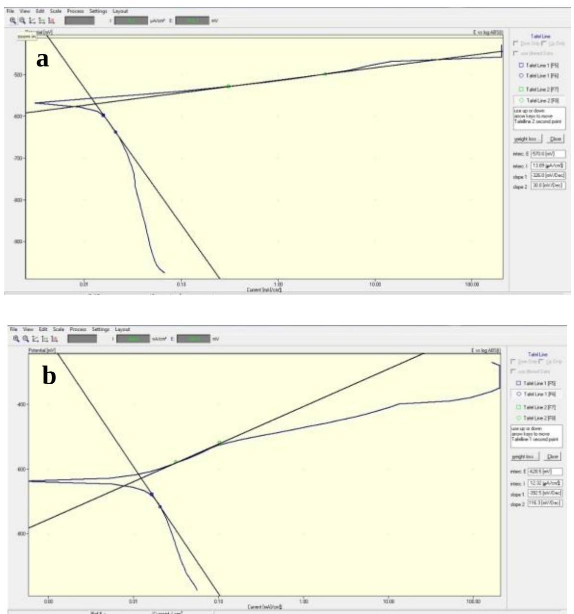

Fig.7 polarization curves of the FSW sample, a) before age heat treatment, b) after age heat treatment respectively in 3.5%NaCl at 30ºC.

4. Conclusion

1. The microstructure of the friction stir welding joints of 2024 -6061 alloys is separated to four zones ; base metal, heat affected zone, thermo mechanical affected zone and stir zone
2. The base alloys have lower corrosion resistance (high Icorr) whereas the FSW samples have high corrosion resistance (lower Icorr).
3. The microstructure of the FSW sample after heat treatment has a finer uniform distribution precipitates.
4. The FSW samples after heat treatment have high corrosion resistance.

5. The precipitation heat treatment after welding process removes the residual stresses in the welding area and lead to reducing the corrosion rate.

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