Structure and media velocity effects on corrosion rate of synergistic weld joint for aluminum alloys 6061 T6

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***Abstract*—Corrosion of welded Aluminum Alloy 6061 T6 was investigated by potential state method in 3.5wt%. NaCl solution.at different velocities (1, 2, and 3) m/ min. Potentiodynamic and open circuit potential measurements were conducted.**

Many specimens prepared for Corrosion test by the dimensions of (15*15*3) mm according to ASTM G71-31 from butt welded joints which obtained using Two different welding processes, tungsten inert gas (TIG) and a solid state welding process known as friction stir welding, TIG welding process carried out by using Rolled sheet of thickness 5 mm to obtain a weld joint with dimensions of (100* 50* 5) mm using ER4030 DE (Al Si_5) as filler metal and argon as shielding gas, while Friction stir welding process carried out using CNC milling machine with a tool of rotational speed 1000 rpm and welding speed of 80mm/min to obtain the same butt joint dimensions. Another butt weld joint processed in the same dimensions subjected to synergistic weld process TIG and FSW weld process at the same previous weld conditions.

Optical Microscopy was used to investigate the microstructure of the specimens which also subjected to micro hardness test.

From corrosion results which obtained by Tafel equation. It was found that corrosion rate for TIG weld joint was higher than the others but synergistic weld process contributed in improving its corrosion resistance by a percentage of 14.3%. Increasing media velocity also contributed in decreasing corrosion rate.

Keywords—TIG Welding, FSW, media velocity, corrosion rate, aluminum alloy

INTRODUCTION

Welding of Aluminum alloys is a critical operation due to the complexity and the high level of defects that may occur during the welding process because Al and its alloys are well known that they are highly reactive with oxygen, they have high thermal conductivity, and they have high hydrogen solubility at high temperature [1] Tungsten Gas Arc Welding (TIG) is one of the most important welding processes; it uses a non- consumable tungsten electrode to produce the weld. TIG is widely used to weld Al-Mg alloys which may influence the mechanical properties of the welded areas by affecting the chemistry of the weld pool .The effect of arc oscillation in either transverse or longitudinal direction is very beneficial to the fusion zone microstructure and tends to reduce sensitivity in hot cracking These problems can be eliminated by Friction stir welding (FSW) process. Friction Stir Welding (FSW) is a solid state joining technique using a tool with a probe attached to its tip rotated while being pushed against the butt sections of the pieces of metal to be welded. The frictional heat generated by this process softens the metal to produce a plastic flow that effectively stirs the metal from the sections on both sides and melting them together to create a weld.[2]

FSW is depended on the welding parameters such as pin rotation speed, traverse speed and stirrer geometry. In order to increase the welding efficiency mechanical properties of joints must be maximized and the defects must be minimized in the friction stir welding (FSW) process [2] [3]

Aluminum alloys will remain the subject of extensive studies due to their susceptibility to localized corrosion in different corrosive environments especially in chloride containing environment, in such corrosion environment Aluminum alloys tend to show pitting corrosion and stress corrosion cracking. Aluminum is actually a very active metal and it instantly reacts with oxygen to form aluminum oxide . This aluminum oxide layer is chemically bond to the surface , and it seals the core of aluminum from any further reaction. This oxide film gives aluminum excellent corrosion resistance in a wide range of water and soil conditions this oxide layer can become unstable exposed to extreme pH levels when the environment is highly or basic acidic . Protective oxide film is generally stable in the pH range of (4.5 to 8.5) , the pH of seawater remains within the domain of stability of the natural oxide film. This explains the good corrosion resistance of aluminum in seawater [4]

This resistance associated with its composition , structure, defect , surface condition and the various types of environments in seawater there for many variable parameters effected the corrosion resistance like speed of media and temperature [5] [6] : moving water is always better than stagnant water if all the parameters are kept constant.

Water movement regularly eliminates corrosion products and uniforms the cathode and anodic zones by removing a possible local excess of H + and OH – ions. In an open circuit moving water is aerates and oxygen take the mission in repairing the oxide layer. In closed circuit the movement of the liquid prevents the

at elevated temperature, resulting in generation of fine and equiaxed recrystallized grains. The dynamic recrystallization grains caused to the density of dislocation of the sample decreased. At the same time, after severe plastic deformation (SPD), the change of actual microstructure of FSW weld sample made the weld chemically homogenized. Based on the principle of electrochemistry formation of deposits under which corrosion can easily develop [5]

Many studies investigate the Corrosion behavior of welded joints:

Yadong Zhao [7] says that in FSW process the material undergoes intense plastic deformation

V.Fahimpour [8] studied the. Corrosion behavior of the welding zone of (FSW) and gas tungsten arc welding (GTAW) methods for AA6061 using Tafel polarization curve, deducting that resistance to corrosion was greater for the FSW grains than the GTAW structure. In both cases, susceptibility to corrosion attack was greater in the welded region than the base metal section

A. Squillace [4] made comparison between tungsten inert gas and friction stir welding and their effect on pitting corrosion for AA 2024-T3 .They found that the weld joints of friction stir welding give the best corrosion resistance results than TIG weld joints because of the influence of the heat input effect and its effect on microstructure

Elsadig. Eltai. [9] Studied the corrosion behavior and the mechanical properties using tensile strength, hardness, and torsion tests of welded and un-welded Aluminum Alloy 6061 T6. The researcher observes that TIG welding caused weakness on specimens that tested for tensile and torsion and there was a significant pitting corrosion on the HAZ compared to the BM.

The aim of this study is to use two ways to investigate corrosion resistance one to use synergistic welding process FSW+TIG and media velocity for aluminium alloy 6061 T6.

EXPERIMENTAL WORK

Metal selection

The material used in this study was Aluminum alloy 6061 T6. The chemical composition of the alloy is shown on Table 1 which was conducted by using ARL Spectrometer.

Table 1 *Chemical Analysis of the used metal 6061-T6 [10]*

Elements w%	Si	Fe	Cu	Mn	Mg	Cr	Zn	Al
Measured value	0.6	0.4	0.3	0.12	1.0	0.2	0.18	Rem.
Slandered value	0.4-0.8	Max 0.7	0.15-0.4	Max 0.15	0.8-1.2	0.04-0.35	Max 0.25	Rem.

Welding joint

Many butt welding joints with dimensions of (100*50*5) were prepared using different methods of welding such as TIG welding Butt joints using argon as shielding gas and ER4030 ($AlSi_{5)}$ as filler material with a chemical composition shown in Table 2, the other parameters were: welding current170 amperes, voltage2 5volts, filler rod diameter 3 mm, welding speed 120 mm/min and gas flow 20 lit/min.

Friction stir welded joint performed by attaching two plates together using CNC milling machine with motor of 11 KW , rotating tool assembly at 1000 rpm rotational speed and welding speed of 80 mm/min. The material for the tool was tool steel which was hardened to58 HRC. The tool used had shoulder diameter of 14 mm, top pin diameter of 5.5 mm, bottom pin diameter of 3 mm and pin height 3.85 mm. The pin was left hand threaded and tool was rotated in counter clock wise direction.

Another butt weld joint processed in the same dimensions by subjecting to synergistic weld process first TIG then FSW weld process.

All welded pieces were tested by X-ray radiography and Faulty pieces were excluded, and the joints without defects used to prepare many specimens for Corrosion test by the dimensions of (15*15*3) mm according to ASTM (G71-31) .

Table 2 *chemical composition of the filler metal (Filer wire ER (4043) Al Si_5 [11]*

Elements Wt%	Si	Fe	Cu	Mn	Mg	Cr	Zn	Sn	Al
Actual value	5.0	0.4	0.1	0.08	0.06	0.25	0.15	0.15	93.44
Nominal value	4.5-6	<0.6	<0.3	< 0.15	< 0.2	-	< 0.1	-	Rem.

Categorizing of specimens

After completing the specimens, they were categorized to groups as shown in Table (3)

Microstructure test

Samples made from a cross- section of the weld joints and base alloy were prepared including: ground, polished and etched and observed under optical microscope in sequences steps.

Wet grinding operation with water was done by using emery paper of SiC with the different grits of (220,320,500, and 1000). Polishing process was done to the samples by using diamond paste of size (1µm) with special polishing cloth.

They were cleaned with water and alcohol and dried with hot air. Etching process was done to the samples by using etching solution (Keller's reagent) consisting of 95 ml distill water, 2.5 ml HNO_3, 1.5 ml HCl and 1 ml HF washed after that with water and alcohol and dried in oven.

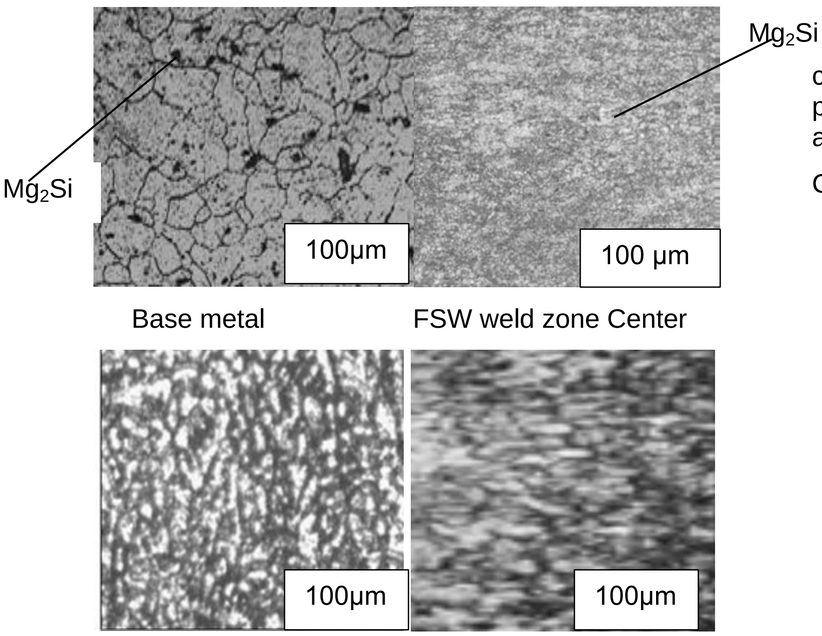
The welded joint samples were examined by Nikon ME-600 optical microscope provided with a NIKON camera,DXM-1200F.the microstructure results are shown in Fig. 1

Hardness test

The Vickers hardness instrument with a 300gf load and loading time of 15 second was used for hardness profile across the weld joint where the results were declared in Fig. 2

Table 3 *categorizing of weld joint specimens*

Sample	***Condition***
A	FSW welding joint
B	TIG welding joint
C	TIG +FSW welding joint



Base metal FSW weld zone Center

TIG weld *one (matrix of base and filler metal) TIG +FSW weld zone

Fig.1 *the microstructure of all specimens*

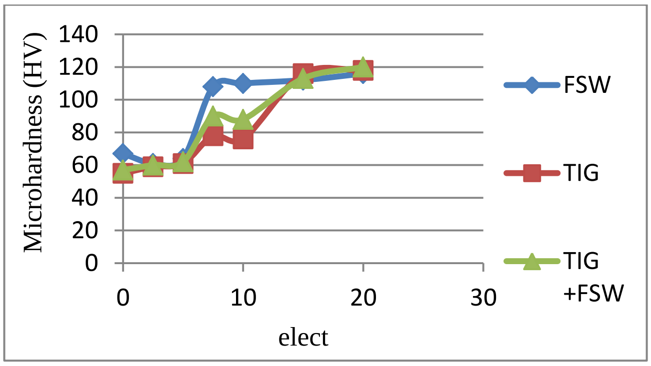


Fig.2 *Micro hardness distribution for the welded joints*

Corrosion Tests

Cell current readings were taken during a short, slow sweep of the potential. The sweep was taken from (-100 to + 100) mV relative to (OCP) which was found during test(-650 mV). Scan rate defines the speed of the potential sweep in mV/sec it was equals 10 mV for each read. The tests were performed by using a WENKING Mlab multi channels potentiostat and SCI-Mlab corrosion measuring system from Bank Electronics-Intelligent control GmbH, Germany 2007, as shown in Fig. 3 In this test, aluminum alloy (6061-T6) weldment samples were used as working electrode (WE), a saturated calomel electrode immersed in the salt solution was used as reference electrode . Media speed changed using a suitable rotating magnetic item to adjust and enhance the sea water velocity as required in this paper (1, 2, and 3) m/min

Electrochemical corrosion test by Tafel extrapolation method was carried out on all samples of weld joint in sodium chloride solution of 3.5% NaCl ˈh pH of 6.8 to determine corrosion Parameters, ɔh as corrosion potential (Ecorr` sion current (i_{corr}) at each media Mg2Si se parameters will leads to calculate ι. .ate according to the equation below [12].

C.R (m.p.y) = 0.13 * Icorr * eq.wt / ρ (1)

Where

m.p.y= mille-inches per year

Icorr=corrosion current density (µA/cm2)

E.W=equivalent weight of the corroding species,

ρ= density of the corroding specimens, (g/cm3).

100µm

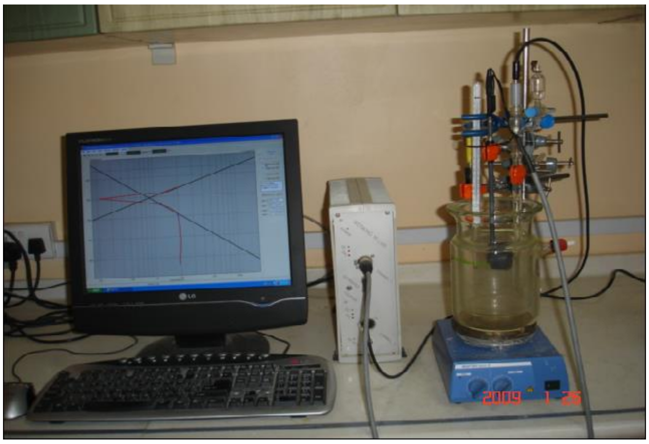


Fig. 3 *The electrochemical corrosion unit*

Results and discussion

Microstructural in Fig. 1 revealed a coarse, elongated grain structure in the 6061-T6 base metal due to presence of alloying elements such as silicon and magnesium precipitation as shown by darken particles Mg_2Si and this microstructure undergoes intense plastic deformation at elevated temperature, by FSW resulting in generation of fine and equiaxed recrystallized grains . The change of actual microstructure of FSW made the weld chemically homogenized. This has an effected on improving corrosion behavior. On the other hand the fusion zone of TIG welded joints contains dendritic structure: is the result of melting which fuses the base metal and filler metal to produce a zone with a composition that is different from that of the base metal. and microstructure causes increasing in corrosion rate this was improved by applying a FSW

on the TIG weld joint which its intense plastic deformation converts the dendritic structure into a smaller grains .

Fig. 2 shows the hardness profile of the weld joints where the TIG weld joint indicated a general reduction in hardness in weld metal and with an increase towards base alloy. This is due to phase transformed induced by fusion weld metal and high temperatures. While FSW weld joints show similar distribution of hardness over weld zone due to the welding processes which produced by the low welding heat that is less than the melting temperature.

Fig. 4 shows the polarization curves of the all specimens which categorized in Table 2 in sea water at different velocities of medium (1,2,3 m/min).these curves show the cathodic and anodic regions. Corrosion potential depends on the electrochemical behaviour of the microstructure and

this is directly dependent on the quantity of the present phases.

Sample (A) gives the least corrosion rate at all velocities compared with other samples because of the fine homogenous grains achieved by FSW, sample B gives high corrosion rate as result of a composition which contained alloying element increased by the melting which fuses the base metal and filler metal but the corrosion rate in sample (C) was lower than that of Sample (B) because of the microstructure improvement for the FSW plastic deformation

The fine precipitates are slightly more anodic than the aluminium matrix. Thus, corrosion potential of the remainder matrix would increase due to dilution of matrix from these elements.

Table 4 *E_{corr}, i_{corr} and corrosion rate for different samples*

Sample	Velocity m/min	E_{corr} [mV]	i_{corr} [μA/cm^2]	corrosion rate (M.p.y) =0.43 i_{corr}
A	1	-768.9	1.899	0.816
	2	-773.6	1.686	0.724
	3	-758.1	1.029	0.442
B	1	-782.6	6.328	2.72
	2	-780.3	6.187	2.66
	3	-778.02	6.009	2.58
C	1	-757	5.392	2.31
	2	-773.9	4.181	1.797
	3	-764.5	3.326	1.43

Fig. 4 also shows that the increasing of media velocity for all weld joints causes a decreasing in corrosion rates because increasing velocity .uniforms the cathodic and anodic zones by removing possible local excess of H^+ and OH^- ions in an open circuit , the removing of this local excess increased by increasing media velocity.

Media velocity at 3m/min for FSW process gives the low corrosion rate by an improving rate of 45.8%.

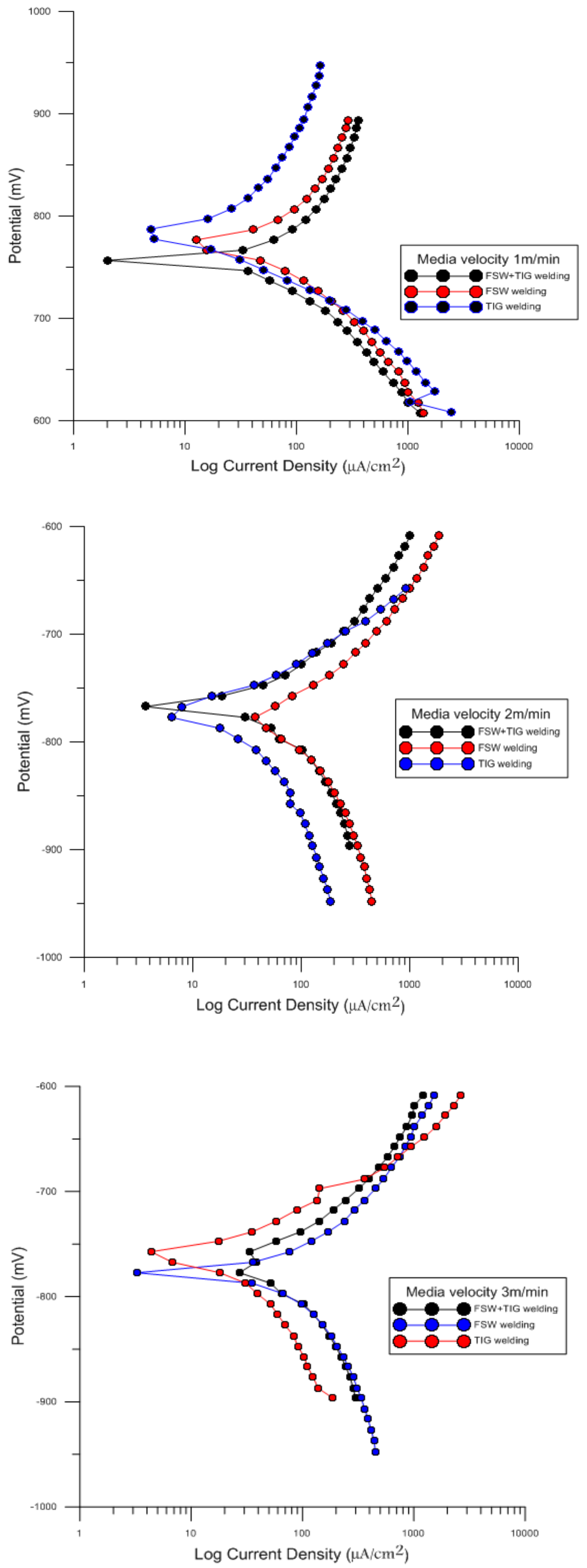


Fig. 4 *the electrochemical behavior polarization for all specimens*

CONCLUSIONS

1-The formation of fine, equiaxed grains and uniformly distributed very fine Strengthening precipitates in the weld region is the reason for higher corrosion resistance

2-The hardness of FSW and FSW+ TIG weld process is higher than that of TIG.

3-TIG welding process shows a general decreasing in Micro hardness due to the higher temperature and slow cooling during welding processes .

4- FSW + TIG welding process improved corrosion resistance comparing with TIG welding process by 14.3%

5- As increasing media velocity corrosion resistance increased for all weld joints.

REFERENCEs

[1] Elsadig. Eltai*, E. Mahdi, Akram Alfantazi The Effects of Gas Tungsten Arch Welding on the Corrosion and Mechanical Properties of AA 6061 T6 Int. J. Elect1 rochem. Sci., pp. 7004 - 7015, (2013)

[2] Klas Weman ,"Welding Process Handbook", Cambridge, England, 2003.

[3] S. Rajakumar, C. Muralidharan, V. Balasubramanian, "empirical relationships to predict grain size and tensile strength of friction stir welded AA 6061-T6 aluminum alloy joints", transactions of nonferrous Metals Society China. 20, pp.1863-1872, 2010

[4] Jon Perry man" A corrosion resistance of aluminum" Crane Materials International January 2007.

[5] Articles" Corrosion of aluminum and aluminum alloys" knowledge articles from www. Key- to – metals .com in international 2005.

[6] P.L. Cabot, F.Centllas, J.A Garrido "Influence of Heat Treatment on the electrochemical corrosion Al –Zn- Mg alloys" Journal of Applied Electrochemistry. October 1991.

[7] Yadong Zhao*1, Qiang H Electrochemical Corrosion Behavior of Friction Stir Welding Weld for 6061 Aluminum Alloy Friction and Wear Research Vol. 1 Iss. 3, October 2013

[8] Fahimpour V., Sadrnezhaad S.K., Karimzadeh F., "Corrosion behavior of aluminum 6061 alloy joined by friction stir welding and gas tungsten arc welding methods ,2012", Materials & Design Volume 39, February, pp. 329–333.

[9] Elsadig. Eltai, E. Mahdi, Akram Alfantazi," The Effects of Gas Tungsten Arch Welding on the Corrosion and Mechanical Properties of AA 6061 T6", Int. J. Electrochem. Sci., 8 pp.7004 – 7015,2013

[10] Metals Handbook, Vol.2 - Properties and Selection: Nonferrous Alloys and Special-Purpose Materials, ASM International 10th Ed.

[11] SAFRA ,Al.Si.5/ER 4043" *www.tesolgroup.com/media-199.pdf*,"

12-Annual Book of ASTM Standards, Standard Practice for Calculation of Corrosion Rates and Related Information, G102-89, Vol. 03.02,2004.