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Corrosion Resistance of TIG Welding Joint for Aluminium Alloy 6061- T6 in Sea Water at Different Velocities

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Abstract :

An experimental investigation has been carried out on microstructure, micro hardness distribution and corrosion behaviour of weld butt joints of 6061 T6 aluminium alloy.

*Arc welding processes by tungsten inert gas (TIG) have been carried out on Rolled sheet of 4mm thickness to obtain many welding joints with dimension of (100 *50* 4)mm using ER4030 (Al Si_5) as filler metal and argon as shielding gas. The other parameters were: welding current 180 amperes, voltage 20 volts, filler rod diameter 1.2 mm, welding speed120 mm/min, gas flow 20 L/min and two passes of the weld*

*All welded pieces were tested by X-ray radiography and faulty pieces were excluded. The joints without defects were used to prepare many specimens for corrosion tests by the dimensions of (15*15*3) mm according to ASTM G71-31 then Optical microscopy was used to observe the welded joint microstructure. Corrosion test was implemented by using potential static polarization measurements in seawater 3.5%NaCl at a temperature of 25℃, and different velocity (1, 2, and 3) m/min. The potential of circuit was determined by open circuit depending on AL in electrochemical series after that the rate of cell's current is changed due to 100± (m v).*

The obtained results by Tafel equation shows that velocity contributed in increasing corrosion resistance of 6061 T6 Al alloy for all specimens and TIG weld joints give low corrosion rats than the bass metal because of changing in microstructure in the weld zone.

Key word: TIG weld , corrosion resistance of Al alloys ,sea water

مقاومة التآكل لوصلات لحام بطريقة ال TIG لسبيكة ألمنيوم 6061- T6 في ماء البحر وبسرع مختلفة

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الخلاصة

فحوصات البنية المجهرية والصلادة المايكروية وسلوك التاكل تم اجراؤها لوصلات لحام تناكبية لسبيكة المنيوم6061-T6لحمت بطريقة لحام القوس الكهربائي باستخدام قطب التنكستن المحمي بغاز الاركون وبابعاد (4*50*100) ملم و بقطب لحام (ER4030 (Al Si_5كمعدن حشو،وبقطر 1.2 ملم وتيار 180امبير وفولتية20فولت وان سرعة تدفق الغاز هي20 لتر / دقيقة وسرعة اللحام120 ملم / دقيقة وبعدد اثنين من التمريرات

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بعد عملية اللحام والتاكد من خلو الوصلات من العيوب من خلال فحصها بواسطة جهاز X-radiography تم تحضير عينات التآكل بابعاد(15*15*3) ملم وفق المواصفة القياسية ASTM G71-31 ثم اتبعتها عمليات تحضير من تنعيم وصقل لاجراء فحص البنية المجهرية باستخدام المجهر الضوئي ذو كاميرا للتعرف على البنية المجهرية لمناطق اللحام اجري اختبار تاكل كهروكيمياوي بطريقة المجهاد الساكن عند جهد حدد من دائرة مفتو حة حسب موقع المعدن في السلسلة الكهروكيميائية ، وبعدها تم زيادة الجهد ب (±100) ملي فولت عند كل 10 ملي فولت يزداد التيار وان وسط التأكل هو ماء البحر وبعد كل اختبار يتم تغير سرعة الوسط (1,2,3) متر/ دقيقة وتم حساب معدل التآكل اعتمادا على معادلة تافل فقد وجد ان مقاومة التاكل للمعدن الملحوم اكثر منها في حالة المعدن الاساس بسبب التغير الحاصل في البنية المجهرية لجميع مناطق اللحام اما عند مقارنة نتائج التأكل لجميع العينات الملحومة وغيرالملحومة وجد انزيادة سرعة حركة الوسط ساهمت في تقليل معدل التأكلدور السرعة في منع تجمع الايونات عند قطب الكاثود ..

Briefs of Expressions used in research

Briefs	Names
ASTM	American system Testing material
TIG	Tungsten Inert GAS
MIG	Metal Inert GAS
GMAW	Gas Metal Arc Welding
HAZ	Heat affected zone
WM	Weld Metal
BM	Base Metal
OCP	Open Circuit Potential
AC	Alternating Current

Introduction

Magnesium and silicon are two major alloying elements in the 6xxx series of wrought aluminium alloys. These alloys are widely used for lightweight structures in Automotive and aerospace industries due to their good extrude ability, weld ability, and excellent corrosion resistance. Welding as a fabrication method is an important manufacturing technology in the aluminium alloy industry .The development of the inert gas shielded welding processes of metal inert gas(MIG) and tungsten inert gas (TIG) have made it possible for joining aluminium alloys [1].

Gas metal arc welding is a process that melts and joins metals by heating them with an arc established between a continuously fed filler wire electrode and the metals. Shielding of the arc and the molten weld pool is often obtained using inert gases such as argon and helium. This is the most widely used arc welding process for aluminium alloy. With TIG welding by using alternating current (AC) polarity and high heat generation end is continuously changing. An electric arc is formed between inconsumable tungsten electrode and the work piece. The arc provides the thermal energy to melt the work piece as well as the filler material for Al alloys ,due to their elevated thermal conductivity, the weld penetration remains very shallow [2] [3].

A great number of problems related to the welding of aluminium and its alloys occur because of the oxide layer, hydrogen solubility, electrical conductivity and thermal characteristics; they all result in crack sensitivity (both solidification and liquation cracking), porosity, and heat affected zone (HAZ) degradation [4]

Aluminium is actually a very active metal and it instantly reacts with oxygen to form aluminium oxide . This aluminium oxide layer is chemically bonded to the surface , and it seals the core of aluminium from any further reaction. This oxide film gives aluminium excellent corrosion resistance in a wide range of water and soil conditions [4].This oxide layer can become unstable exposed to extreme PH levels. 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 aluminium in seawater [5].

This resistance associated with its compos ion, structure, defect , surface condition and the various types of environments in seawater we can see that many variable parameters effecting on the corrosion resistance such as speed of media and temperature: moving water is always better than stagnant water if all the parameter are kept constant.

Water movement regularly eliminates corrosion products by uniforms the cathode and anodic zones and removing a possible local excess of H + and OH – ions. in an open circuit moving water and oxygen aerates to up takes the mission in repairing the oxide layer in closed circuit the movement of the liquid prevents the formation of deposits under which corrosion can easily develop [6] [7]

Many studies have investigation the corrosion resistance of aluminium weld joint alloy in seawater

NurAzhaniAbdRazak [1] studied the effect of heat treatment on the corrosion behaviour of TIG welded AA6061 aluminium alloy . He found that the WM region behaves as a cathode and shows better corrosion resistance under various conditions as compared to the BM area and the heat treatment process improves corrosion resistance by increasing the potential of the BM specimens towards more positive values.

A. Squillace. [4] made comparison between tungsten inert gas and friction stir welding and their effect on pitting corrosion .They found that the weld joint of fraction stir welding give the best result than TIG weld joint because of the influence of the heat input effect and its effect on microstructure

Aendraa Azhar and mohammed Faized [8] studied the effects of different fillers on microstructure and tensile properties of welded AA6061-T6using GMAW process. The result it show that the major alloying element such as Si and Mg play an important role in determining the microstructure and mechanical properties.

Rajesh Manti [9]describes the effects of pulsed TIG welding process parameters (pulse duration, peak current, and pulse frequency) on the microstructure and micro hardness of Al-

0.8%Mg-0.5%Si (6061) alloys. It was observed that pulse TIG welding produced finer grain structure of weld metal than conventional TIG welding (without arc pulsation).and some instances that, an increase in the pulse frequency has been found to refine the aluminium and eutectic grain structure of weld metal especially when welding is done using short pulse duration. Long pulse duration lowers the pulse frequency up to which refinement of constituents in weld metal takes place.

The aim of the present study is to investigate the effect of the velocity of the media on the corrosion behaviour of the welded AA6061 aluminium joint using ER Si_5 as filler wire

Experimental work

Aluminium alloy Rolled plate 6061T6, which it chemical composition is listed in **Table 1**

Table .(1) Chemical Analysis of the used metal AA 6061- T6 [13]

Elements w%	Si	Fe	Cu	Mn	Mg	Cr	Zn	Al
Nominal 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.
Actual value	0.6	0.4	0.3	0.12	1.0	0.2	0.18	Rem.

was machined to the required dimensions (100 * 50 * 4) mm then the plates were butt welded (two pass for each side) using the TIG process as shown in **Figure.(1)**.

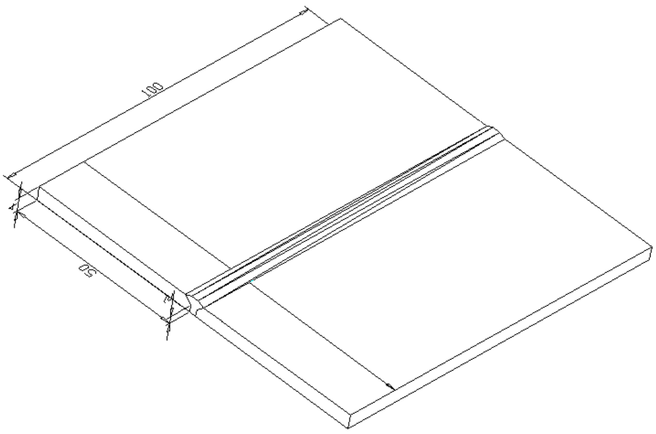


Fig .(1) TIG welding joint (dimensions in mm)

The plates were cleaned before the TIG welding procedure with a scraper and acetone. In the TIG welding process, a Jasic type semiautomatic welding machine was usedwithER4030 ($AlSi_5$) as filler material its chemical compassion is shown in **Table (2)** and argon as a shielding gas. The other parameters were: welding current 180-190amperes, voltage 20-21 volts, filler rod diameter 1.2 mm **Table (3)**

Table .(2) Chemical composition of the filler metal (Filer wire ER 4043) Al Si5 [14]

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

Table .(3) welding conditions

Welding layer	Filler Diameter mm	Current (Amp)	Voltage (V)	Gas Settings (L/Min)	Wire speed mm/min
1	1.2	180	20	20	120
2	1.2	190	21	20	120

All welded pieces were tested by X-ray radiography and faulty pieces were excluded. The dimensions of the Corrosion test sample were (15*15*3) mm according to ASTM (G71-31) Symbol (A) was given to specimens without welding and symbol(B) to specimens of TIG weld joint. Optical microscopy was used to observe the welded joint microstructure and base metal. The specimens are treated with Sic emery paper of grades (120,350,500,800).Then were polished with cloth and alumina Al_2O_3 solution. Etched by Keller's reagent consisting of 95 ml distil water, 2.5 ml HNO_3, 1.5 ml HCl and 1 ml HF.

The Vickers hardness profile of the weld zone was measured on a cross section perpendicular to the welding direction using micro hardness tester with4.5N for 10sec

The Corrosion test was carried out in solution which consists of

A 35 gm of sodium chloride (NaCl)and 1000 gm of distilled water. The pH ratio was measured by a pH meter and it was found 6.9.

Corrosion tests were carried out by using potential stat tests to obtain the micro cell corrosion rates. In the tests, cell current reading was taken during a short, slow sweep of the potential. The sweep was taken from (–100 to +100) mV relative to (OCP) Scan rate defines the speed of potential sweep in mV/sec. In this range the current density versus voltage curve is almost nearly linear. A linear data fitting of the standard model gives an estimate of the polarization resistance, which is used to calculate the corrosion current density (Icorr) and corrosion rate. The tests were performed by using a WENKING MLab multi channels and SCI-Mlab corrosion measuring system from Bank Electronics- Intelligent controls GmbH, Germany The prepared specimen of area 1cm x 1cm was fixed in the holder. The reference electrode was fixed about (1 mm) away from the surface of the specimen to be tested. The reference electrode used in this study was saturated calomel electrode (SCE). The auxiliary electrode used in the electrochemical cell was platinum type. The specimen holder (working electrode), together with the reference and auxiliary electrodes were inserted in their respective positions in the electrochemical cell.

This potential stat is able to induce a constant potentials ranging from (–1 to + 1V), the potentials of the standard reference electrode used in this study (SCE). The potential difference between the working and the reference electrode (WE - RE) and any current passing in the circuit of working electrode can be measured by using the SCI Computer Software and can be automatically recorded. The results and plots were recorded using window XP. The scan rate can be selected. The recorded current density was used in the calculation of the corrosion rate using Tafel extrapolation method .The results are shown in in **Table** [4]and **Figure(3)**.

Table (4) .Ecor, Icor and corrosion rate for different samples

Sample	Temperature °C	Velocity m/min	Ecorr [mV]	Icorr [μA/cm^2]	corrosion rate (Mpy) =0.43 Icorr
A	25°C	1	-636.5	105.32	45.28
	25°C	2	-720.9	89.74	38.58
	25°C	3	-709.6	58.7	25.2
B	25 °C	1	-768.9	18.99	8.615
	25 °C	2	-773.6	16.86	7.25
	25 °C	3	-758.1	10.29	4. 42

C.R (m.p.y) = 0.13 * I_{corr} * eq.wt / ρ[10] …………………. **(1)**

Where

m.p.y= mille-inches per year

I_{corr}=corrosion current density (μAcm2)

E.W=equivalent weight of the corroding species =27/3,

ρ= density of the corroding species, (g/cm3) =2.7.

Results and Discussion

The weld region of AA6061T6, when welded with $AlSi_5$filler metal usually contains lower amount of strengthening precipitates compared to the base metal region. Therefore, the strengthening of Mg_2Siprecipitates is weak in TIG joints contains that alloying elements similar to the base metal. The base metal contains coarse and elongated grains with uniformly distributed strengthening precipitates.. The fusion zone of TIG welded joints contain dendritic structure and this may be due to fast heating of the base metal and fast cooling of molten metal due to welding heat**. Figure (2)**

The higher strength of the base material is mainly attributed due to presence of alloying elements such as silicon and magnesium. These two elements combine and undergo precipitation reaction and form strengthening precipitates Mg_2Si as shown by darken particles in **Figure.(2)**

Micro hardness results **Figure(3)**, shows the micro hardness distribution for TIG and base metal. The micro hardness of the base metal was 115Hv. The micro hardness of TIG joint in the weld metal region was 65 Hv. This shows that the hardness is reduced in TIG joint due to higher heat input and use of lower hardness $AlSi_5$ filler metal[11][12]

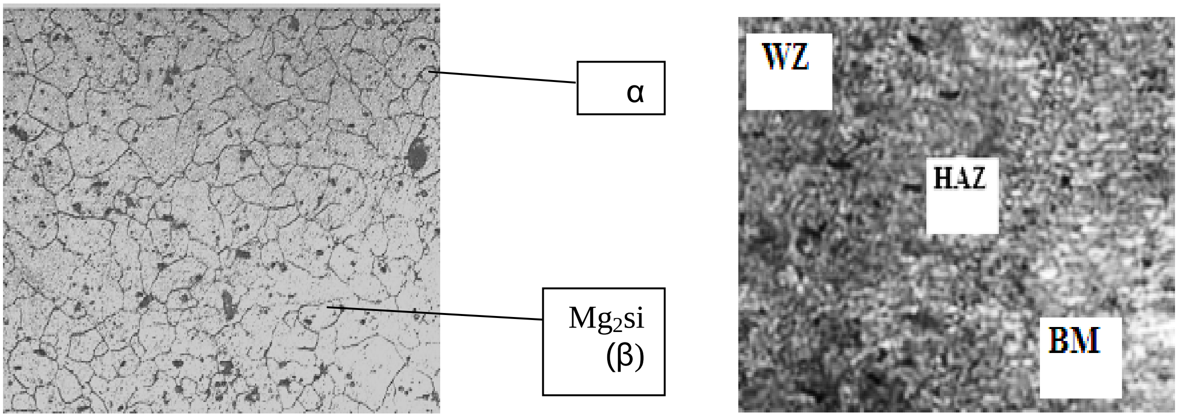


Fig .(2) Microstructure of TIG welded joint of AA 6061-T6 at (100 X)

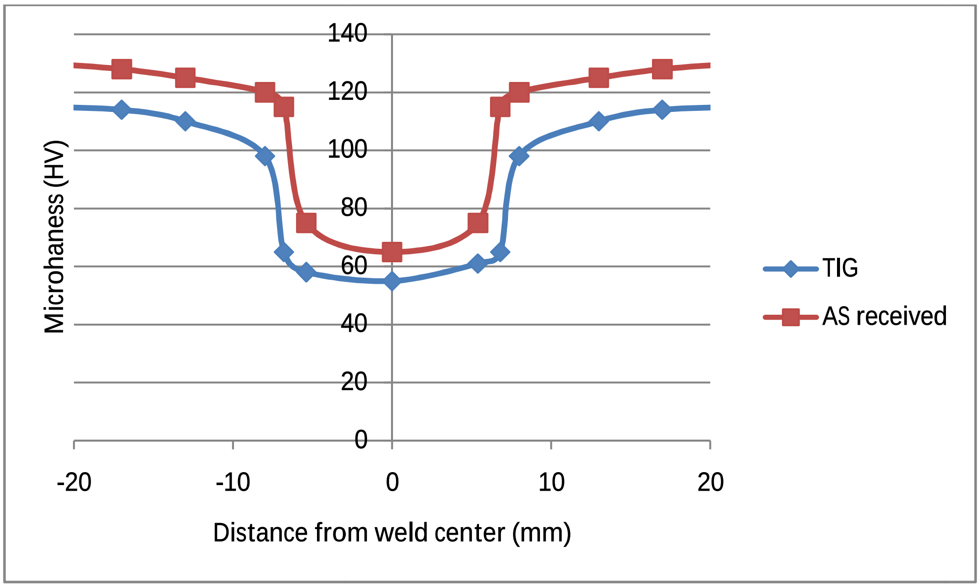


Fig .(3) Micro hardness of all specimen

Corrosion behaviour

The BM and WM potential stat polarization curves for specimen A and specimen B in seawater solution are shown in **Figure 4.,Figure(5)**

According to the graph, the WM specimen exhibits a higher corrosion potential in both conditions as compared to the BM specimen. It is attributed to the high silicon content in the weldment. Silicon in solid solution condition has a tendency to increase the dissolution potential of aluminium. The WM area behaves as cathode and the BM is an anode.

Based on results obtained from polarization measurements in **Table 4**, corrosion potential depends on the electrochemical behaviour of the microstructure and this is directly dependent on the quantity of the present phases. Course inter metallic particles that are enriched from magnesium and silicon would lead to dilution of matrix from these alloying elements Therefore, dilution of matrix from magnesium and silicon tends to be the main reason for anodic behaviour of the BM specimen (Sample A). According to fine precipitates of magnesium silicide (Mg_2Si) would form and dispersed throughout the matrix [1]

These 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. Based on Table4, it is confirmed that there is an increase of corrosion potential

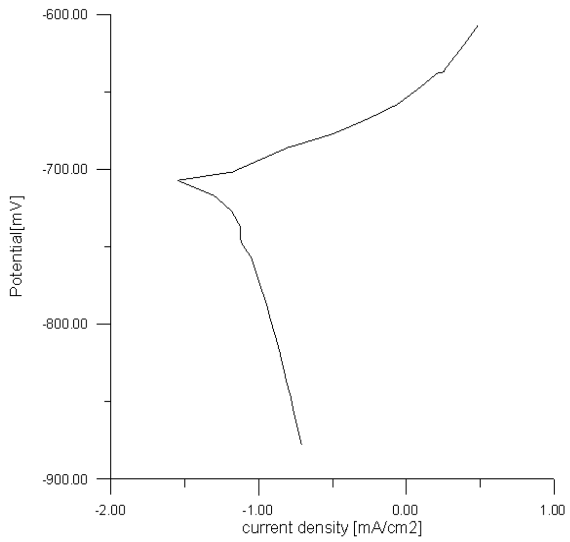
For Sample A. The BM showed higher corrosion rate than the WM in all conditions. The higher

corrosion rate in BM is contributed to the presence of secondary phases in the microstructure.

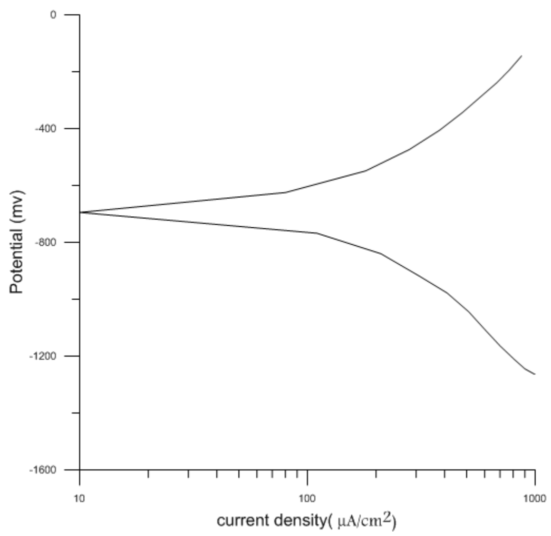
These particles are different than the matrix, thus, a potential difference occurs between them.

Inter metallic particles are found to be favourable sites for cathodic reaction as compared to Al matrix [1]

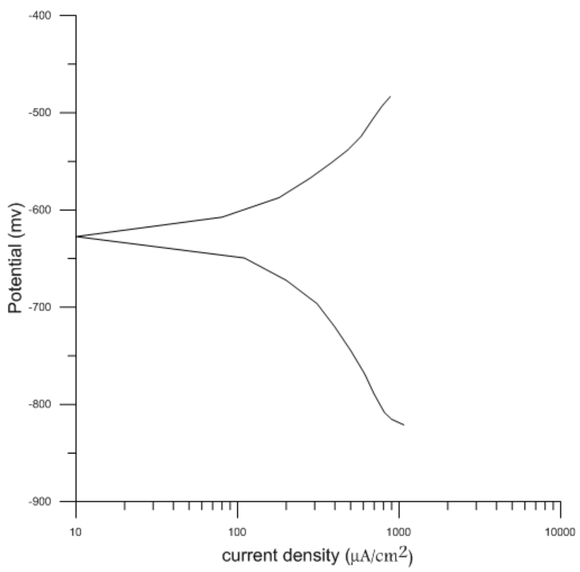
on the other hand we see when velocity increase causes an increasing in corrosion resistance for all specimens A and B because velocity uniforms the cathode and anodic zones by removing possible local excess of H + and OH – ions by that it will eliminate these ions from complaining with chloride ions to form acidic or alkaline media. AL can with is tend a water flow speed up to (2,3 - 3) m/s without any risk of corrosion [6] .All welding specimens B gives lower corrosion at different speed compared with base metal because of the metallurgical changing in microstructure during welding.



Speceimen (A) at1m/min



Speceimen (A) at 2m/mi



Speceimen (A) at 3m/min

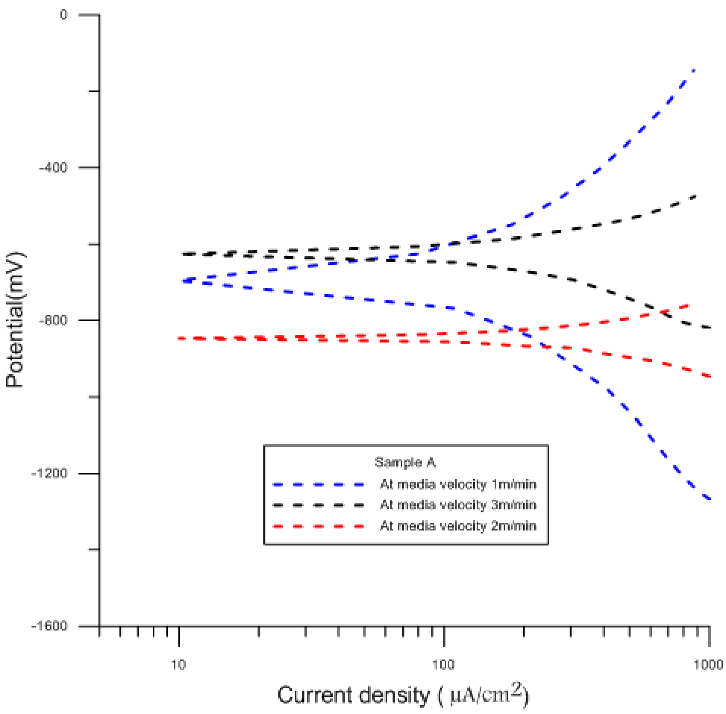
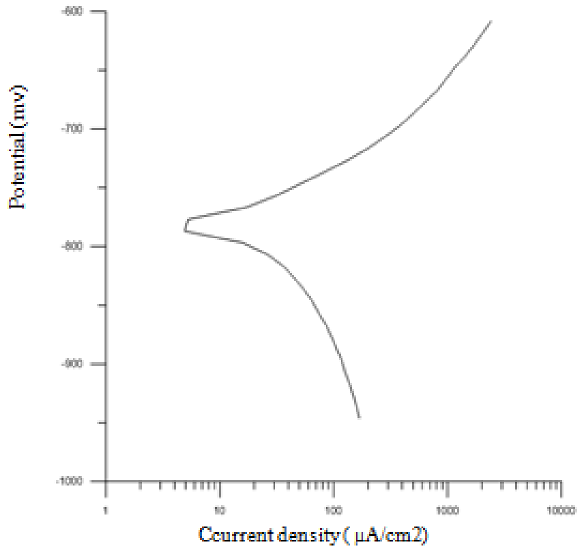
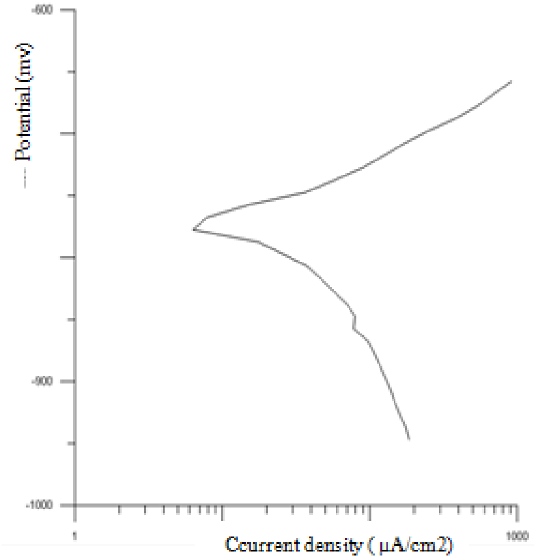


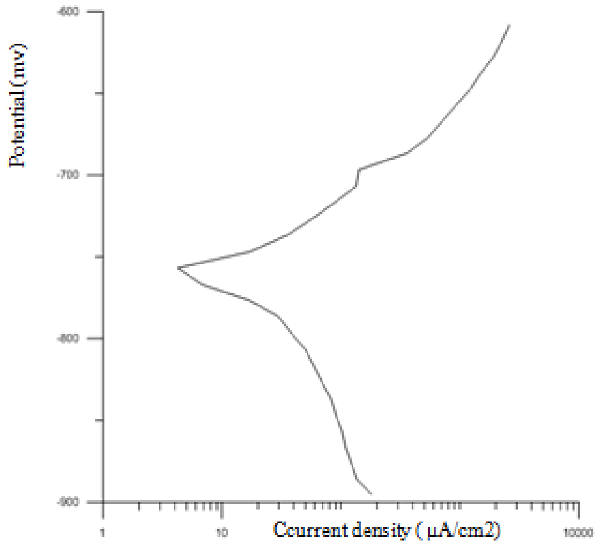
Fig .(4) the electrochemical behavior polarization for specimen(A) at different velocity



Speceimen (B) at 1m/min



Speceimen (B) at 2m/min



speceimen (B) at 3m/min

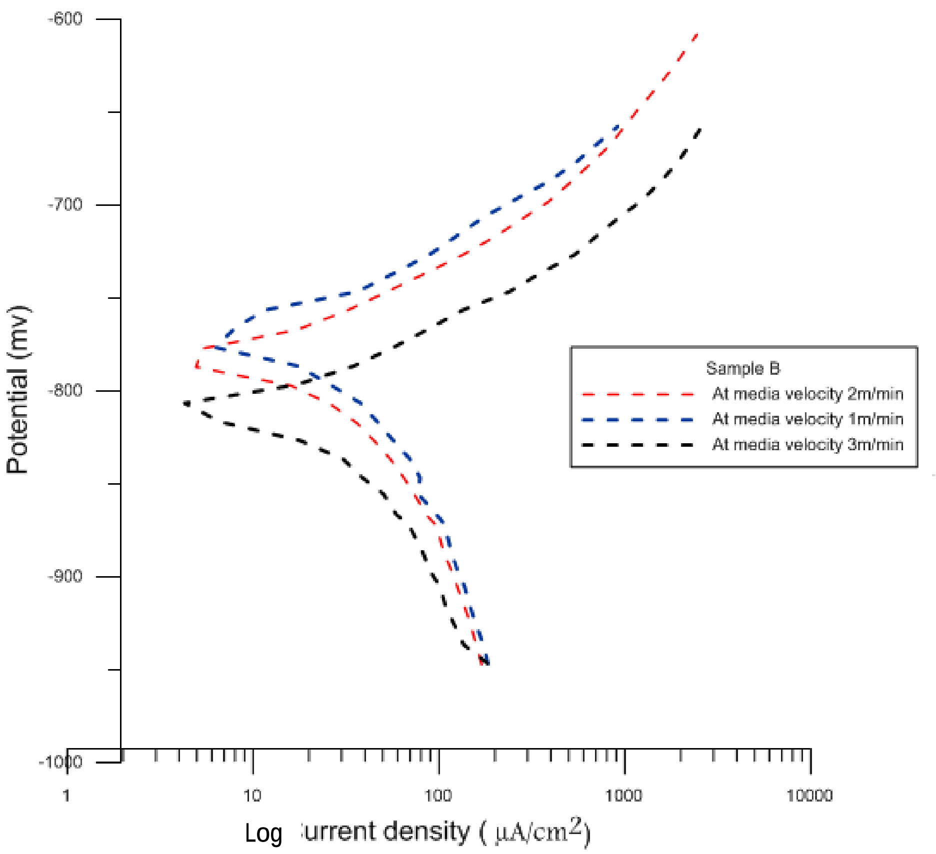


Fig .(5) the electrochemical behavior polarization for specimen(B) at different velocity

Conclusions

On the basis of experimental investigation carried out on welded joints of AA 6061 T6 prepared according to TIG processes, the following conclusions are given:

1. Corrosion rat for a welding joint can be controlled by the correct selection of filler metal.
2. An increasing in media velocity has contributed to a decreasing corrosion rat for all specimens since it prevents oxygen from dissolving in sea water.
3. Media velocity and filler metal have an important role in decreasing corrosion rat.

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