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CORROSION BEHAVIOR OF DISSIMILAR FRICTION STIR WELDED FOR ALUMINUM ALLOYS (5052 H34 AND 7075 T6)

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Abstract: Friction stir welding was used widely in joining of dissimilar Aluminum alloys joints which used in aerospace applications due to high specific strength and superior corrosion resistance. Aluminum alloys 5052 H34 and 7075 T6 was successfully welded at tool rotation speed (400) rpm and travel speed (187) mm/min with using adjustable scrolled pin tool. Corrosion behavior of this joint was investigated using potentiostat in two medias "0.5% HCl, 0.5% NaOH" to show the polarization resistance and calculate the corrosion rate from data of "Tafel extrapolation method". The microstructures of different zones of FSW joint have been investigated. Cyclic polarizations were done to measure the resistance of specimens to pitting corrosion. From the results obtained, it has been shown that best corrosion resistance of welded joint was noticed in 0.5% NaOH comparing with 0.5% HCl. The corrosion rate of FSW welded joint was higher than base alloys in 0.5% NaOH, while it's lower than base alloys in 0.5% HCl. The Base metal alloys susceptible to pitting corrosion while friction stir welded joint exhibit good general and pitting corrosion resistance in NaOH and HCl media.

Keywords: *Aluminum alloys, Friction stir welding, corrosion rate, potentiostat and Tafel extrapolation*

سلوك التآكل لوصلات ملحومة بالخلط الاحتكاكي لسبيكتي الالمنيوم (5052 H34 و7075 T6)

الخلاصة: استخدمت طريقة اللحام بالخلط الاحتكاكي بشكل واسع في ربط سبائك الالمنيوم المختلفة المستخدمة في التطبيقات الفضائية وذلك لخفة وزنها وارتفاع مقاومتها النوعية ومقاومتها العالية للتآكل. تم لحام سبائك الالمنيوم 5052 H34 و7075 T6 بنجاح عن سرعة دورانية 400 دورة/دقيقة وسرعة لحام 187 ملم/دقيقة وباستعمال اداة ذات مسمار مسنن. كما تمت دراسة سلوك التآكل لها باستخدام "المجهاد الساكن" بوسطين هما: 0.5% حامض الهيدروكلوريك 0.5 % هيدروكسيد الصوديوم لبيان مقاومة الاستقطاب وحساب معدل التآكل من قيم طريقة "تافل الاستقرائية. كما تم فحص البنية المجهرية عند مناطق لحام مختلفة من الوصلة. الاستقطاب الحلقي تم اجراءه لقياس مقاومة التآكل النقري للعينات. من النتائج التي تم الحصول عليها تبين ان أفضل مقاومة تآكل لوصلة اللحام عند الغمر بمحلول هيدروكسيد الصوديوم بتركيز (0.5%) بالمقارنة مع حامض الهيدروكلوريك بتركيز (0.5%) .ان معدل التآكل لوصلة اللحام عند الغمر بمحلول هيدروكسيد الصوديوم أعلى منه بالنسبة للمعدن الأساس بينما يكون معدل التآكل لوصلة اللحام أوطأ من المعدن الأساس عند الغمر بمحلول حامض الهيدروكلوريك. لقد بينت النتائج ان سبائك المعدن الأساس يكون عرضة للتآكل النقري مقارنة بوصلة اللحام التي أبدت مقاومة تآكل جيدة ضد التآكل النقري والتآكل العام عند الغمر بمحلول هيدروكسيد الصوديوم وحامض الهيدروكلوريك بتركيز (0.5%).

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1. Introduction

Friction stir-welding (FSW), is a modern solid-state joining technique, it was invented by The Welding Institute (TWI) [1]. The technique advantage is by reduction of porosity in addition to solidification cracking and enhance the weldment properties of joining light metals alloys [2]. FSW is perfect for joining aluminum alloys; specially the 2xxx, 5xxx and 7xxx series which are commonly used in automotive, shipbuilding and aircraft products, railway rolling stock industries and most likely others [3,4], because they are light in weight, easy to machine and have relatively high tensile strength. Such alloys are usually welded using FSW not traditional fusion welding. Welding by friction stir was done efficiently for joining of main structures in Eclipse 500™ jet [5].

Venugopal et al. [6] studied microstructural and pitting corrosion properties of friction stir weld of 7075 Al alloy in 3.5%NaCl solution. Corrosion resistance of weld metal is better than that of TMAZ and base metal. Friction stir welding of alloy 7075 resulted in fine recrystallized grains in a weld nugget which has been attributed to frictional heating and plastic flow.

For alloys with elevated strength, such as 7075, the maximum susceptibility to intergranular corrosion was shown in heat-affected zones for the weld, which is due to copper depletion over the grain boundaries [7]. In the previous years the corrosion behavior was investigated for FSW aluminum alloys [8]. Commonly, it was found that the nugget zones are more vulnerable to corrosion than the base metal. Buchheit [9] and Paglia [10] assessed the stress corrosion cracking exposure of friction stir welded 7050-T651 and 7075-T7451, by SSRT method in solution of NaCl. Peening methods, such as laser and shot peening, can be accommodating in mitigating the residual stresses on the surface, and subsequently improve the fatigue strength and stress corrosion cracking. Trdan et al. [11] established that the AlMgSiPb alloy specimens after corrosion analysis were illustrated to be a higher resistance to corrosion than AlSi1MgMn aluminum alloy. Osterkamp et al. [12] recognized that the role of the tool pin in friction stir-welding is to shear the material to its back side during the tool movement, and the implanted rotating pin transports the material at both sides of the joint line to the plastic state, with aid of frictional heat input by the shoulder.

The aim of the present work is to study the microstructures and corrosion resistances of dissimilar friction stir welded joint of Al alloys (5052 H34 and 7075 T6) and its behaviors in different Medias by polarization technique.

2. Experimental work

Aluminum alloy 7075-T6 (Al–Zn–Mg–Cu), is one of the best aluminum alloys which is used widely in industrial. While the aluminum alloy 5052-H34 (Al-Mg) is soft alloy used in marine and automobile applications due to its high formability, Table (1) explains the chemical composition of used alloys. A combination of these alloys was friction stir welded at conditions of 400 rpm rotational speed, 178mm/min feed rate, tilt angle of 2^o and forging force of 11KN, using threaded adjustable tool as shown in

Figure (1). Plates have the dimension of 600*200*4.8 mm (length x width x thickness) were friction stir welded. This joint was shown as in figure (2).
First cross section of weld samples with 40mm length x 10mm width had been mounted then grinding and mirror polishing were done prior to corrosion test. Microstructure examinations were done before and after corrosion test.

Corrosion test was done for many mounted samples (base alloy 5052-H34, base alloy 7075-T6 and joint of (7075-T6 with 5052-H34) have square dimensions of 10 mm side. Corrosion tests were carried out in different medias of "0.5% HCl and 0.5% NaOH" by using "WINKING M Lab 200" Potentiostat with electrochemical standard cell with provision for working electrode, auxiliary electrode (Pt electrode), and a Luggin capillary for connection with an saturated calomel electrode (SCE) reference electrode. Electrochemical measurements were performed with a Potentiostat at a scan rate 3mV/sec. The main results obtained were expressed in terms of the corrosion potentials (E_{corr}) and corrosion current density (i_{corr}) in addition to measure the "Tafel slope".

3. Results and discussion

3.1 Macro and Microstructure examination

The macro and microstructure study prior to corrosion show elongated grain in the base zone while fine equiaxed grain was shown in the weld zone due to thermo-mechanical stir action force as shown in figure 3. While the microstructure of FSW joint after corrosion tests reveal uniform corrosion attack in two medias, as shown in figure 4. 3.2 Corrosion behavior

The "open circuit potential" (OCP) measurement is considered as an important parameter for evaluating the stability of the passive film of the specimens. Tables 2 and 3 show all the corrosion data. These data are deal with other works **[13].**
Comparison between corrosion behaviors of two base alloys (5052-H34 and 7075-T6) and FSW welded joint when immersed in NaOH (0.5%) solution was made. It's clear that a decrease in corrosion rate of joint compared to the base metals due to decrease of i_{corr} of the joint. While a higher corrosion rate (increase in i_{corr}) was noticed in the welded joint compared to the base metals when immersed in HCl (0.5%) solution.
Tafel slope of base alloys and welded joints were shown as in Figures (5 to 10) respectively.
These figures show the cathodic and anodic behavior of these samples. Figures (5 to 7) show the polarization curves of base alloys (5052-H34 and 7075-T65) and weld joint in 0.5% NaOH solution. All figures indicate the cathodic and anodic regions, where the reduction of oxygen and dissolution of aluminum can take place respectively. Corrosion parameters measured by Tafel extrapolation of potentiodynamic curves. These data which listed in Table (1) can be summarized as follow:

1- Corrosion potential shifts toward more noble value for weld joint compared with these for base alloys.

2- Corrosion current density highly increased; while 7075-T65 alloy had the lowest current density may due to formation of protective layer of passive film.
3- Cathodic and anodic Tafel slopes were increased for weld joint because of increasing the sites on cathodic and anodic region due to stir welding.
4- Corrosion rates and polarization resistance values confirm the increasing the sensitivity to corrosion in the case of welding compared with base alloys.

Figures (8 to 10) show the polarization curves of base alloys and weld joint in 0.5% HCl solution, where the reduction of hydrogen can occur at cathodic sites, while the oxidation of aluminum will take place at anodic sites. Corrosion parameters of unwelded and welded specimens indicate that the corrosion potential became more negative for weld joint and the corrosion current density highly increased due to increasing the anodic sites on the surface. Also, cathodic and anodic Tafel slopes were influenced by welding. Corrosion rate was increased and the resistance decreased for welded alloys. This work is agreed with other research [14].

When we compared between the behaviors of weld joint in both corrosive media, can be seen that base alloys and welded joint have corrosion resistance in HCl higher than in NaOH solution due to consume the oxygen in cathodic reaction more than react it with aluminum ions to form passive film:

$$O_2 + 2H_2O + 4e \rightarrow 4OH^- \quad (1)$$

Figures (11 to 16) show the cyclic polarization of bases alloys and weld in 0.5% NaOH and 0.5% HCl. Fig.12 shows Cyclic polarization for base alloy 7075-T6 in 0.5% HCl, from which it has been shown that base alloy 7075 exhibit pitting corrosion, that was clear when the anodic curve rises to -500 and then return and cut itself at potential -650V and i_{corr} 1.1 mA/cm^2. Other figures revealed that all alloys have good resistance to uniform and pitting corrosion.

4. Conclusions

1. Best corrosion resistance of welded joint was noticed in 0.5% NaOH comparing with 0.5% HCl.
2. The corrosion rate of FSW welded joint was higher than base alloys in 0.5% NaOH, while it's lower than base alloys in 0.5% HCl.
3. The base alloys and weld joint showed good resistance to uniform and pitting corrosion in NaOH and HCl medias.

Table (1) chemical composition of used alloys in FSW

	Mg	Cr	Si	Fe	Cu	Mn	Zn	Ti	Others	Al
AA7075	2.5	0.25	≤0.4	≤0.5	1.7	≤0.3	5.5	≤0.2	≤0.15	Balance
AA5052	2.5	0.25	≤0.25	≤0.4	≤0.1	≤0.1	≤0.1	-	≤0.15	Balance

Table (2) Corrosion parameters in 0.5% NaOH solution for base alloys and weld joint

Material	E_{corr} (mV)	i_{corr} (μA/cm2)	-bc	ba	CR (mm/y)	Rp Ω.cm2
5052-H34	1199	29.99	94.2	109.9	0.327	0.734
7075-T65	1039	15.01	100.4	74.4	0.164	1.236
Weld	935.7	175.85	140	118.0	1.910	0.158

Table (3) Corrosion parameters in 0.5% HCl solution for base alloys and weld joint

Material	E_{corr} (mV)	i_{corr} (μA/cm2)	-bc	ba	CR(mm/y)	Rp Ω.cm2
5052-H34	573.8	44.75	78.2	66.7	0.488	0.349
7075-T65	731.8	17.80	201.2	49.6	0.194	0.97
Weld	1408	468.89	124.6	119.2	5.100	0.0564

Fig.1 Friction stir welded Tool

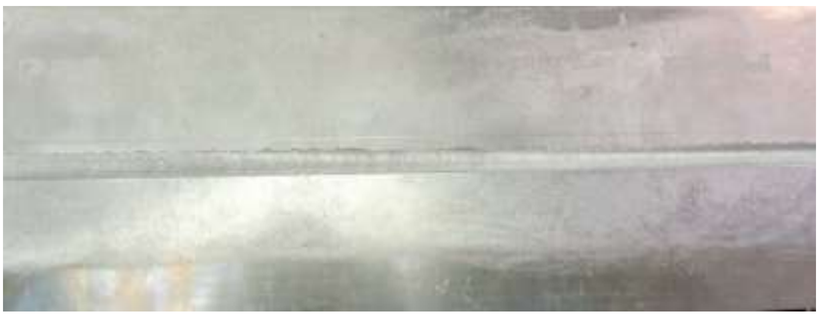

Fig.2 Welded joint of Al –alloys (5052 H34 with7075 T6)

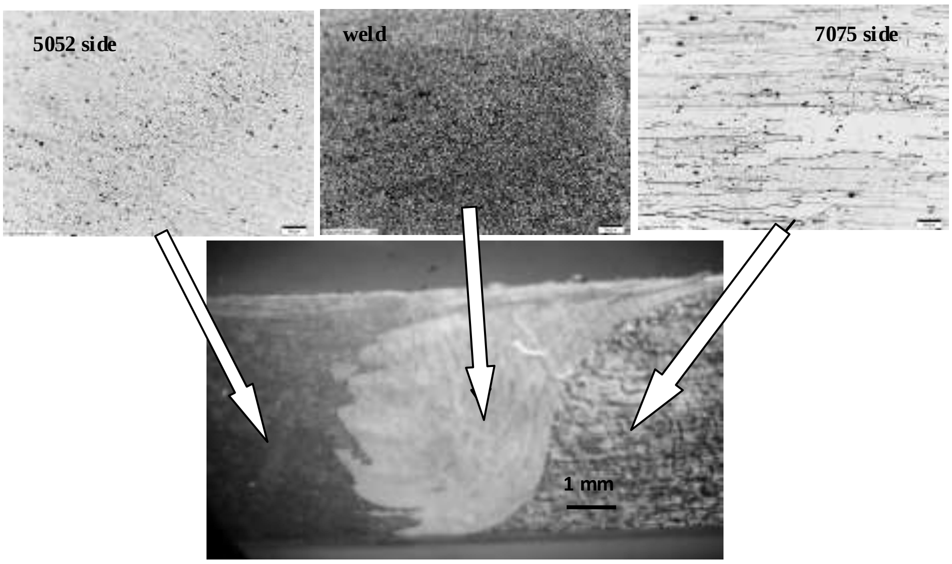

Fig.3 Macro-Micro structural examination of FSW (5052 H34 and 7075 T6) joint

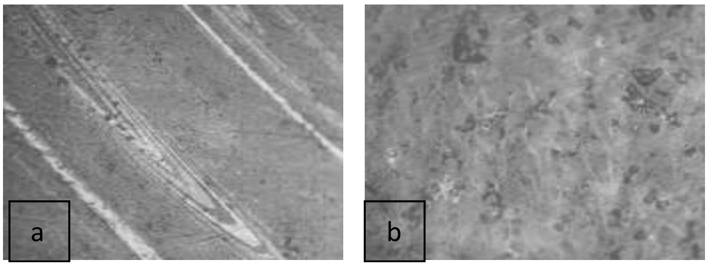

Fig.4 Microstructure of weld zones for FS joint exposed to different Medias (400x)

0.5% HCl, b- 0.5%NaOH

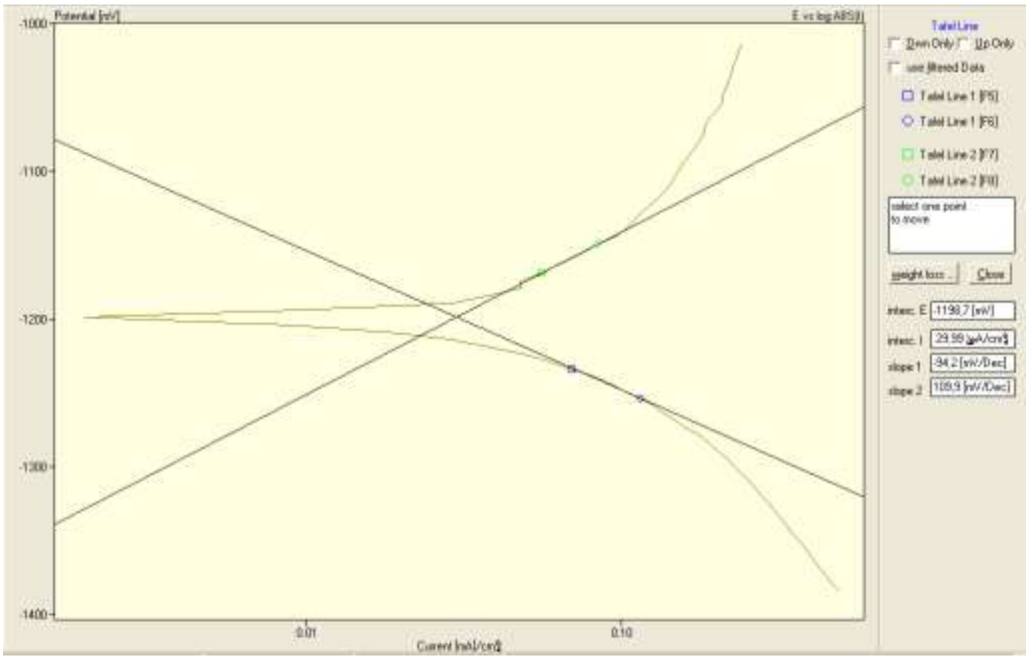

Fig.5 Polarization curve of base alloy (5052 H34) in 0.5% NaOH solution

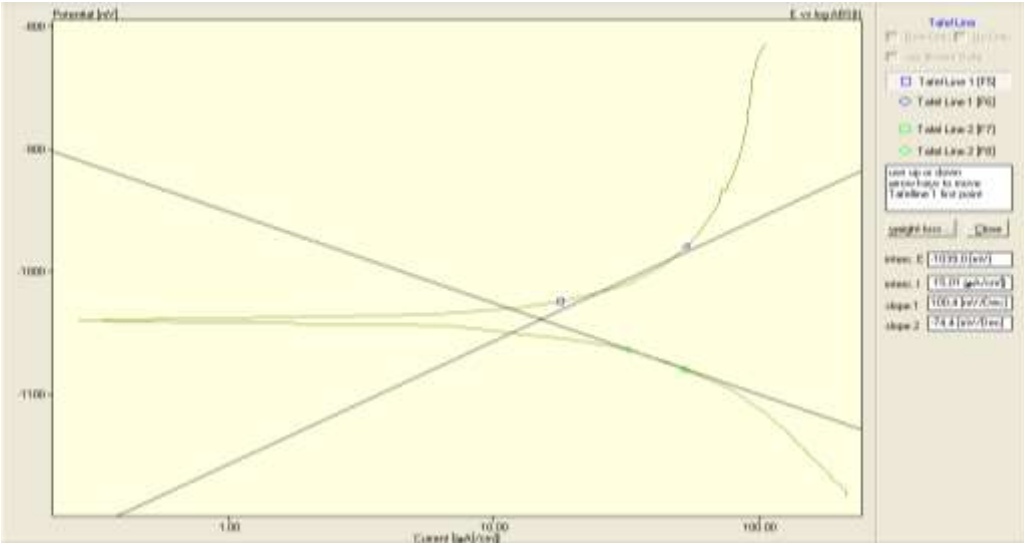

Fig.6 Polarization curve of base alloy (7075 T65)) in 0.5% NaOH solution

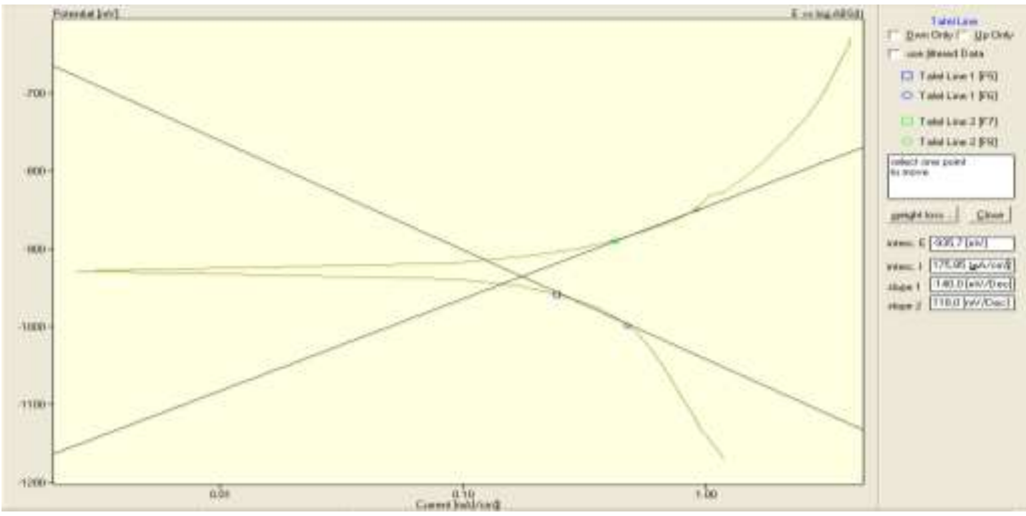

Fig.7 Polarization curve of weld joint in 0.5% NaOH solution

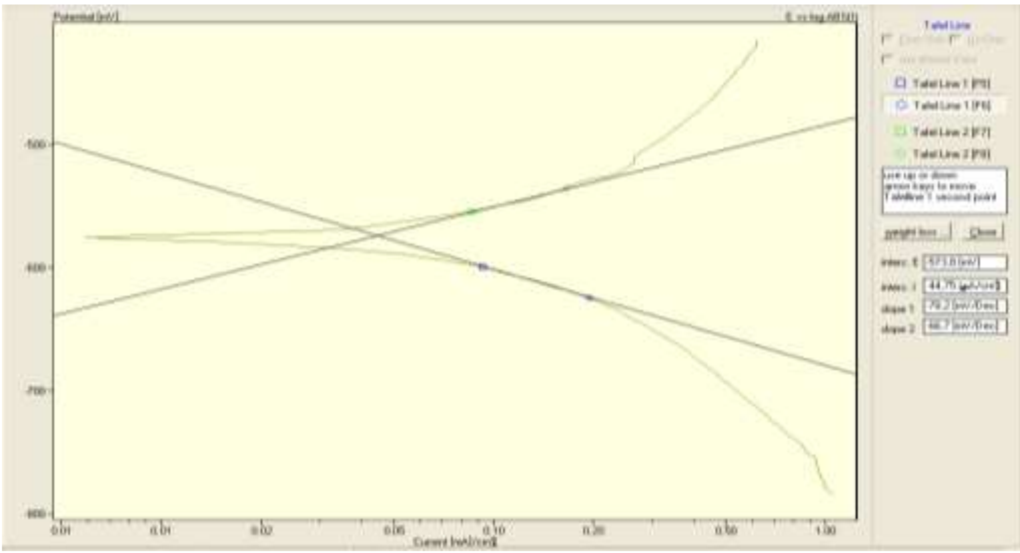

Fig.8 Polarization curve of base alloy (5052 H34) in 0.5% HCl solution

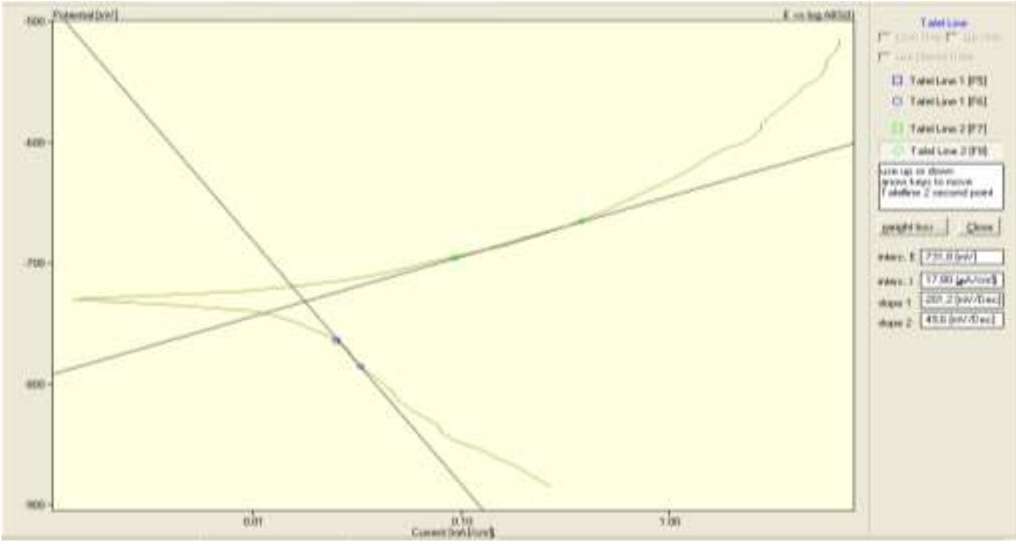

Fig.9 Polarization curve of base alloy (7075 T65)) in 0.5% HCl solution

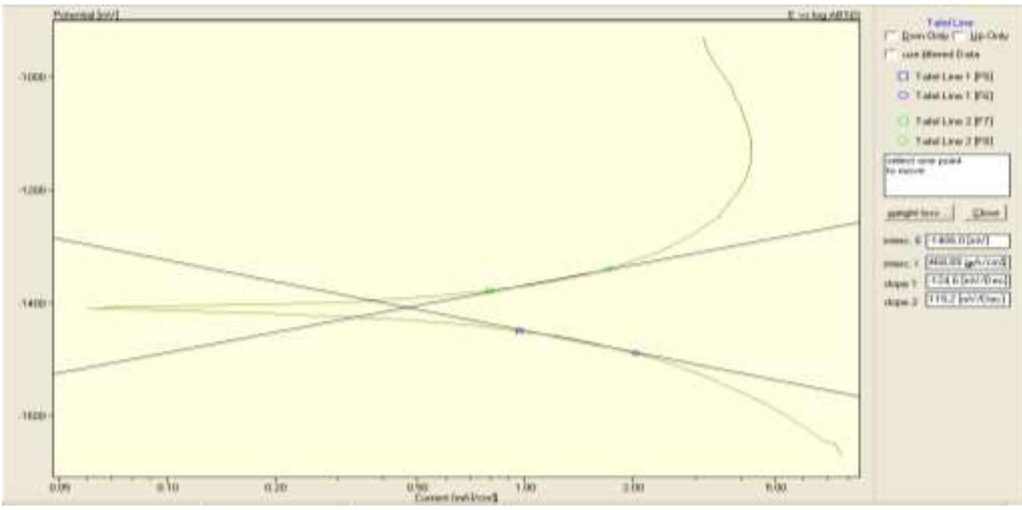

Fig.10 Polarization curve of weld joint in 0.5% HCl solution

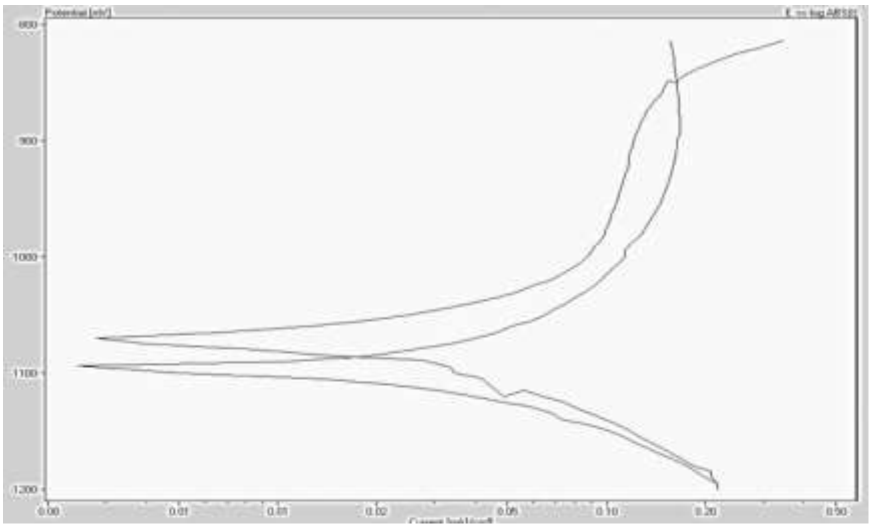

Fig.11 Cyclic polarization for base alloy 7075-T6 in 0.5% NaOH

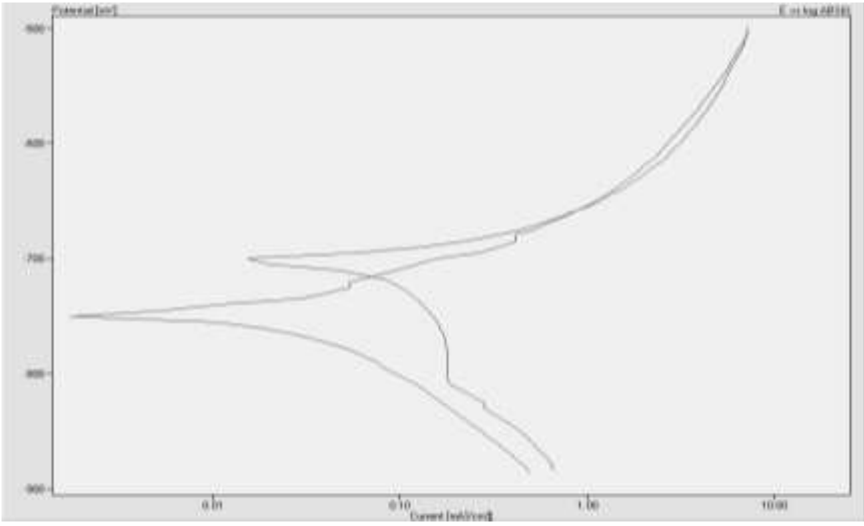

Fig.12 Cyclic polarization for base alloy 7075-T6 in 0.5% HCl

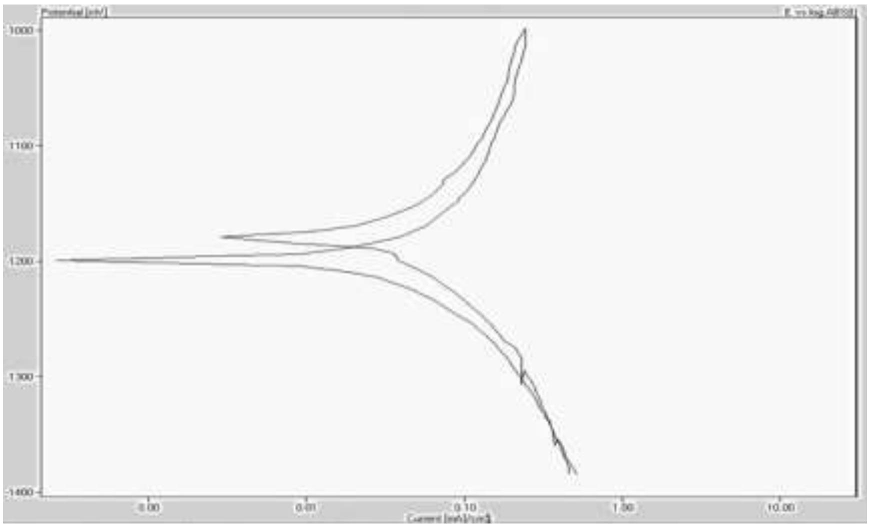

Fig.13 Cyclic polarization for base alloy 5052-H34 in 0.5% NaOH

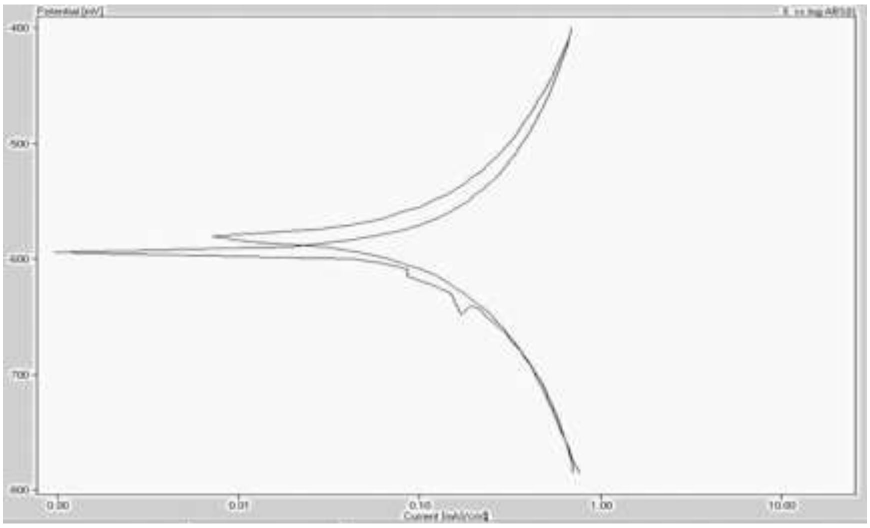

Fig.14 Cyclic polarization for base alloy 5052-H34 in 0.5% HCl

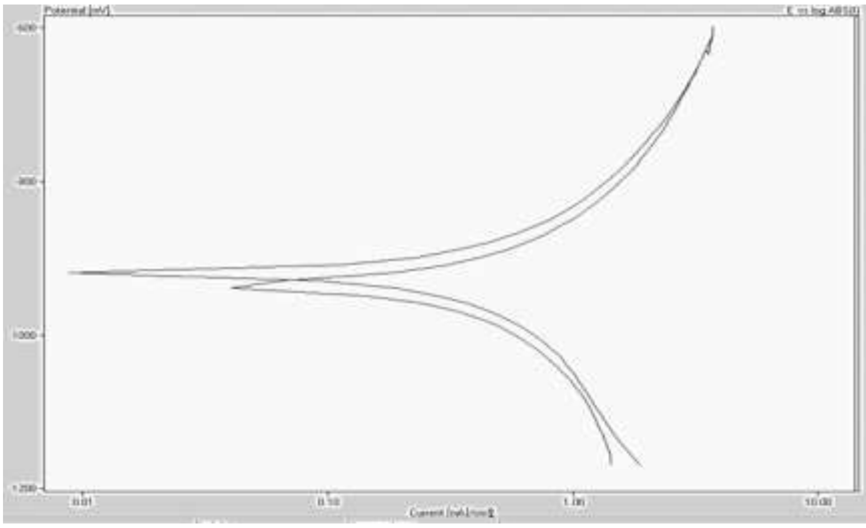

Fig.15 Cyclic polarization for FSW weld joint in 0.5% NaOH

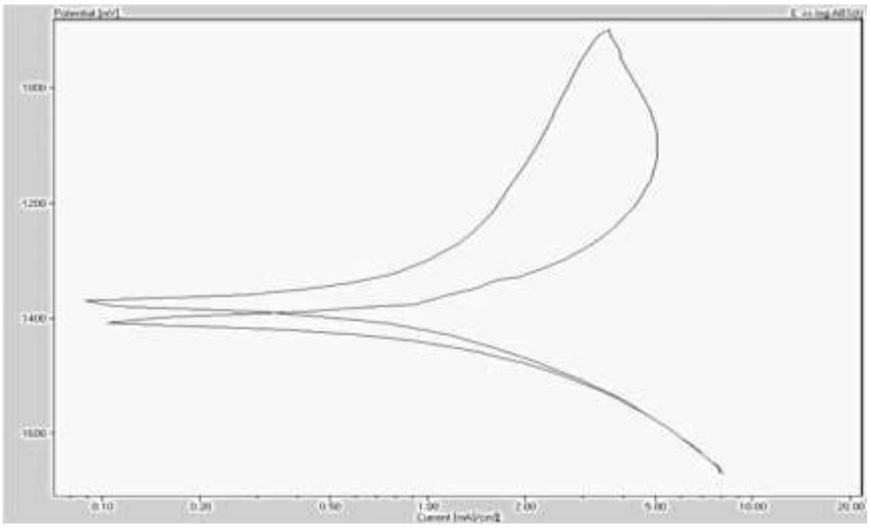

Fig.16 Cyclic polarization for FSW weld joint in 0.5% HCl

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