THE EFFECT OF MEDIA TEMPERATURE ON THE CORROSION BEHAVIOR OF MIG WELDED AA 6061-T6 JOINTS +

Sawsan Abdul Shaheed Abbas AL-Zubaidi *

Abstract:

The purpose of the present paper isto identify theinfluences ofMetal inert gas joiningmethod on the behavior of AA 6061 -T6 joints' regarding corrosion. Many experiments have been performed to test the rate of the corrosion of this alloy. Metal inert gas (MIG) welding processhas been performedonplates having a thicknessof 6mm to producemultiple buttwelding connectionswithmeasurements of (100 *50* 6)mm,withmarginalangle of single and twofold V of 70^{0}byfiller metal having symbol ER-4043 and Argon as a protecting gas. The connected pieces are examined byX-ray radiography.

The welded joints were treated by heat, the joints heated for half an hour in the stove to 150 C° then cooled in the air to releasethe connecting stresses.Numeroussampleswere providedfor the corrosion examination inmeasurements of (15*15*3) mm agreeing to ASTM G71-31 from the weld joint and the base metal, then the microstructure was examined. The corrosion test was achieved by potentiostatic polarization measurements in 3.5%NaCl seawater at various temperatures (25, 50, 75°C). It was found that the corrosion rate for the base metal decreases as the media temperature increasesbecause the increasing temperature prevents the oxygen from dissolving in the water and accelerates the chemical reaction between the metal and the oxygen forming aprotective layer. Besides, the results of the corrosion rate for the weld joints showed a noticeable decrease for the same reason and for the change in the microstructure during the welding.

Keywords: **MIG Welding process, Al alloys 6061-T6, corrosion behavior, filler metal.**

تأثير درجة حرارة الوسط على سلوك التأكل لوصلات ملحومة بطريقة MIG من سبيكة المنيوم 6061-T6

سوسن عبد الشهيد عباس

المستخلص:

هدف البحث دراسة تأثير عملية لحام القوس الكهربائي المتحققة بطريقة MIG على سلوك التأكل الكيمياوي لسبيكة المنيوم 6061-T6 , اذ تم استخدام صفيحتين من المعدن في لحام وصلة تناكبيه بالأبعاد(6*50*100) ملم بعد عمل زاوية لحام تحضيرية من جهة واحدة ومن جهتين مقدارها70درجة على شكل حرف (V) باستخدام سلك لحام نوع -4043ERوالاركون كغاز حماية.

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*Lecturer in Technical Institute / Al-Forat Al-Awsat University / NajafTechnicalInstitute

بعد عملية اللحام والتأكد من خلو الوصلة من العيوب من خلال فحصها بواسطة جهاز X-ray , radiographyاجريت معاملة حرارية تضمنت تسخين الوصلة في فرن كهربائي عند درجة حرارة 150 درجة لمدة نصف ساعة ثم التبريد بالهواء بهدف ازالة الاجهادات الناتجة من عملية اللحام .

تم تحضير عينات اختبار التآكل من وصلة اللحام والمعدن الاساس بأبعاد(3*15*15) ملم وفق المواصفة القياسية ASTM G71-31 ثم تلاها عملية فحص البنية المجهرية، وطبق اختبار التآكل الكهروكيمياوي بطريقة المجهاد الساكن في ماء البحر بتركيز 3.5%من كلوريد الصوديوم عند درجات حرارة مختلفة(75,50,25) درجة مئوية.ومن النتائج التي تم الحصول عليها وجد ان معدل التآكل يقل بزيادة درجة حرارة للمحيط لعينات المعدن الاساس كون ان الحرارة تمنع ذوبان الاوكسجين في الماء وتعمل على تعجيل التفاعلات الكيمياوي بين الاوكسجين والمعدن مولدة طبقة الاوكسيد الواقية من التآكل وكذلك بالنسبة للعينات الملحومة اذ وجد ان معدل التآكل يقل عند ارتفاع درجة الحرارة لنفس السبب الوارد ذكره وكذلك بسبب التغيير الحاصل بالبنيةالمجهرية و الناتج من حرارة عملية اللحام.

Introduction:

Heavytask structures such as trucks, railroad cars, furniture, high compression applications, pipelines and seaapparatuses demand high corrosion resistance [1]. One of the most proper Aluminum alloys for this task is AA6061 Aluminum alloy [1]. However, many complications arise during the welding of Aluminum alloys,including those related to their inherent qualities such as the high thermal conductivity, thehighsolubility of the Hydrogen at elevated temperature, as well as the chemical reactivity with Oxygen . Thechiefgoal is to further decrease in the Mg_2Si ratio in the original metal of Aluminum byadequatestuffing alloy to decrease cracking possibility in weld metal [2].

ER4043 (Al-Si_5%) and ER5356 (Al-Mg5%) are two different types of a filler metal which are used separately depending on the requirements of the welding necessities.

As a fact, seawater causes corrosion to all alloys and metals when they are exposed to it, which is an electrochemical process. Besides, they have different corrosion potential which is known as electrical potential,according to the levels of the seawater alkalinity or acidity. These metals protectthemselves by creating an oxide layer to avoidthe corrosion, which is possible if the oxide layeris tightly adherent, self-healing, as well as stable. However, if the layer isuntied, crumbly, and non-self-mending, like oxidation on steel, then the corrosion will endureunnoticed. Nevertheless, the highly stable oxides might be stricken when the chloride environments are concentrated by hydrochloric acid. Numerouskinds of destructive assaults can affect the structures, ships, and other constructions used in marine water service [3, 4]. Media temperature affects the corrosion resistance which increaseswith the rise in temperature. Temperature prevents oxygen from dissolving in the water and forming a protective layer of AI which is automatically combined. The temperature accelerates the chemical reaction between oxygen and metal to forma layer which can never be combined after 120 ºC [5].

Many studies investigate the paper subject and some of these studies are listed below:

Elsadig. O. Eltai[4] studied the special effects of MIG welding process on the corrosion behavior in 3.5% (wt.) solution at room temperature, in addition to the mechanical qualities of welded and un welded joints. The results illustrated that the heat-affected zone (HAZ) is more susceptible to corrosion than the original metal (BM) and the corrosion on both HAZ and BM ispitting in nature. In addition to that, the corrosion potential of HAZ is largely variable compared to BM ,and the corrosion potential of the BM displays no changes compared to the totalsoakingperiod,in addition to thepresence of voids at the welding zone.

The corrosion pattern of Aluminum alloy AA 6063 in sea water was studied by W. B. Wan Nik, O. Sulaiman [6] in 2010. An inhibitor was used in several different concentrations, and the corrosion process was studies using electrochemical spectroscopy EIS, electrochemical potential dynamic repetition, as well as potentiodynamic polarization. A morphological assessment was essential to notice the appearance of a thin layer on the study sample. It was found that the corrosion varies according to the different concentrations of the inhibitor used, as observed through the data of the electrochemical spectroscopy.

Metal Inert Gas weldingis considered an essential welding process for the aluminum alloys assembly as demonstrated by BatainehOmar [7]. MIG process conditions determine its success which translates into high break-resistance and excellent quality welding joints. Among the process factors studied, filler feed rate and the voltage of arc were the only two important factors. Specimen edge angle, gas flow rate, and pre-heating temperature were not of particular significance. The welding strength reached its maximum mean at optimum filler feed rate of 7 in per second and an optimum arc voltage of 24 volts.

As demonstrated by Seong-Jong KIM[8], Aluminum alloys utilised in marine constructions exhibit admirable levels of corrosion resistance in addition to a melting point that is relatively minimal. Sea water of a natural composition has been utilised to conduct electrical tests on Aluminum alloys of 5000 Al-Mg and 6000 Al-Mg-Si subtypes. Anodic/Cathodic polarization, Tafel analysis, in addition to several other tests were carried out to observe the corrosion behavior. It was revealed through these investigations that the 5052-O alloy has the most resistance to corrosion in marine ambient constructions.

In this work the influence of metal inert gas weld joints on corrosion behavior is investigatedfor aluminum alloys 6061-T6

Experimental Work

Aluminum alloy AA 6061- T6 has been selected for study. The chemical analysis of the alloy is listed in Table (1)which is done using ARL Spectrometer.

Welding process

Sheets of 100 mm long, 25 mm wide and 6 mm in thickness of 6061-T6 aluminum alloys were welded together with the preparation edge angle of single and double V joints of 70° using GMAW process to obtain Butt joints as shown in **Fig.(1)** With dimension of (100, 50, 6) mm

ER4043 (Al-Si_5) is employ as a filler metal rod, the chemical analysis of the rod is listed in **Table (2)** which isdone using ARL Spectrometer in the general company of Heavy Engineering Apparatus in Baghdad.

Sheets are cleaned with a scraper and acetone Previously the joining then sheet are butt joined (two pass for both side) using a MIG-350 type semiautomatic joiningdevice byfactorslisted in Table (3).welding Heat input is animportantvariable affecting liquid flow,heat transfer and mass transfer and thermal cycle in the pool. It is computed as follows [11]:

Heat Input = I*V*60/ S-----------------(1)

Where:

I: welding current (Amp)

V: arc voltage (Volts)

S: welding speed (mm/min)

The outcome is listed in table (3) and fig.(2) shows the weld joint photograph.

Then numeroussamples for Corrosion examination from weld joint are equipped using the measurements of (15*15*3) mm agreeing to ASTM (G71-31).

Categorization of equipped specimens .

The equipped of the samples, they are classified to groups as shown in **Table (4)**

Microstructure test

Microstructure from base material and the variationsin weld zone are examined by optical microscope. For microstructure test,samplesare equippedcontaining followingsetup:-

1-Grinding by Sic emery paper in diverse grits of (120, 240, 500,800, and 1200).
2-Polishing by diamond paste of size (0.3μm) with special polishing cloth, and washedusing alcohol and water then dehydratedusing hot air.
3-Etching for the structure by using Keller's reagent consisting of 95 ml distill water, 2.5 ml HNO_3, 1.5 ml HCl and 1 ml HF, then washed after that. Optical microscopy using computerized ME-600 microscope with a Nikon camera was performed on the samples, the examined result was shown in Fig.(3)

X-Ray Diffraction

Classified Specimens having symbol (A , B ,) in **Table (4)** are subjected to X – ray diffraction examinationby x-ray diffraction meter in Ministry of science and technology.Thetestresults in phase analysis graphare exposed in table (4).

Corrosion Tests

Evaluationsof current cell which is obtainedthrough a short scavenge laggard for the potential. The scavengeis obtainedfrom (-200 to + 200) mV comparative to (OCP) which are taken at each (10)mV/sec.The current density voltage curve is nearly linear in this extent. A linear data appropriate of the typical model offersa measure of polarization resistance, which in turn, can be utilized to determine the corrosion rate and its current density (Icorr). The examinations are conductedthrough SCI-Mlab corrosion measuring system and a WENKING Mlab multichannel potentiostat (Bank Electronics-Intelligent control GmbH, Germany 2007), as shown in Fig.(5) In this examination, weldmentspecimens and base metal represent the (WE) working electrode.The reference was a saturated calomel electrode in salt solution.

Electrochemical corrosion examinationusing Tafel extrapolation techniqueis perform on all specimens by sodium chloride solution have 3.5% NaCl and PH of 6.8 at different temperatures (25,50,75) to define corrosion Factors, like corrosion potential (Ecorr) and corrosion current (Icorr) at each media temperature . The obtained result implemented in equation (1) to evaluate the corrosion rate agreeing to its [12].

$$C.R\ (m.p.y) = 0.13 * Icorr * eq.wt / \rho \qquad (1)$$

Where
m.p.y= mille- per year
Icorr=corrosion current density (μA/cm2)
E.W=equivalent weight of the corroding species,
ρ= density of the corroding specimens, (g/cm^3).

Results and Discussion:

Microstructure shown in **Fig (3 A)** appears as a granularextended grain structure inthe original metal because of the existenceof alloying elements in the form of silicon and magnesium sedimentationasdarken particles Mg_2Si and **Fig.(4A)** show Al phases with small amount of Mg_2Si **Fig (3B,C)** contains dendritic microstructure due to welding heat input which dissolvethe base metal and stuffingmetal to fabricate anarea with a dissimilar composition fromthe basemetal.Therefore, the strengthening of Mg_2Si settlement is weak in MIG process **Fig(4B).**This dissimilarity in composition creates a galvanic couple, which canaffect the corrosion method in the neighboring of the weld. This offersmicrostructure galvanic effect due to insulation consequent from solidificationproduced by the fast elevation in original metal temperature during welding, combined with fast reduction in temperature of molten metal.

Specimens(B) in **Fig (3 B)**contains of a weld changeof wrought base metal during a HAZ and into solidified weld metal and contains micro structurally indifferent regions as the fusion zone, HAZ zone.

Fig.(6,7,8) show the polarization curves of the three specimens, respectively, which are classified in **Table(4).** The corrosion potential of each specimenrelies on themicrostructure's electrochemicalbehaviour. Besides that, this behaviour depends directly on the amount of the existing phase. This can be linked to the heterogenousmicrostructure and the temperature changes. The increasing temperature gives a decreasing corrosion rate due to the effect of the temperature on oxygen which prevents it from dissolving in water. As a consequence, a protective layer of AL will form and automatically combined because of the accelerating effect of the temperature on the chemical reaction between the oxygen and the metal [5].

Fig.(7,8) demonstrate the effect of elevation in water temperature on the specimens B and C. There is a reductionin I_{cor}measureand the corrosion rate for the same reason mentioned above.

The corrosion rates for the specimens (B, C) areless than in specimen (A) at different media temperatures **Fig.(9)**due to the effect of MIG welding method. This methoddecreasesthe precipitates of alloy elements (Si, Mg) that are cleared before. These elements combine with oxygen and form the elements oxide which is accelerated by temperature, instead of Aluminum oxide film which is thinning as temperature increased.

When comparing corrosion rates between specimens (B) and (C), the corrosion rate in specimen (C) is less than that in specimen (B)due to the weld joint shape which increases the filler metal and by that increasing the precipitated metals particularly silicon element giving the chance to increase the elements oxide.

Insample C at 75 °C, the corrosion rate is the lowest for both the effects of weld joint shape and microstructure which is mentioned before.

Conclusions:

1. In the MIG welding zone, the change in the chemical analyses is theresultof the combination of the filler with base metal thatexerts the chief influence on corrosion behavior.
2. Increasing media temperature causes decreasingcorrosion rate for base metal due to the heterogeneous microstructure and the temperature effect in preventing oxygen from dissolving in water and encouragesforming oxide film with alloying elements.
3. In the MIG process, high heat intensity touches the microstructure zones in the weld joint.

4. The lowest corrosion rate is at media temperature of 75 °C for double –v joint as the precipitate elements increase in combination with dissolved oxygen.
5. Weld joint shape (preparation angle) affects the corrosion rate, and corrosion rate in single butt welded joint is less than the corrosion rate in double-v joints due the change in chemical composition.

References :

1- Alfredo S. Ribeiro and Abelio M.P, "*Fatigue Behavior of Welded Joints Made of 6061-T651 Aluminum Alloy*", www.intechopen.com

2- AendraaAzhar Abdul Aziz, "*Effects of Different Fillers on Microstructure and Tensile Properties of Welded AA6061-T6,* "Key Engineering Materials" Vols. 462-463 (2011) pp 1189-1193

3- P.JohnMaclins, "*Tensile Behavior of Aluminum Alloy 6063-T6 in Sea water*", Journal of Engineering Research and Development Volume 10, Issue 5 (May 2014), PP.68-74

4- Elsadig. O. Eltai and E. Mahdi, "*The Corrosion and Mechanical Properties of AA 6061 T6 Joined By MIG Welding Method*", Proceedings of Global Engineering, Science and Technology Conference 3-4 October 2013

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

6- W.B. Wan Nik, O. Sulaiman, "*corrosion behavior of aluminum alloy in seawater*", The International Conference on Marine Technology, 11-12 December 2010, Buet, Dhaka, Bangladesh 175

7- Omar Bataineh, "*Optimizing Process Conditions in MIG Welding of Aluminum Alloys through Factorial Design Experiments*", Latest Trends in Environmental and Manufacturing Engineering, 2012, pp.21-26

8-Seong-jong KIM, Seung-jun LEE " *Electrochemical characteristics of Al−Mg and Al−Mg−Si alloy in sea water*" Trans. Nonferrous Met. Soc. China 22(2012) s881−s886

9- Metals Handbook, Vol.2 - "*Properties and Selection: Nonferrous Alloys and Special-Purpose Materials*", ASM International 10th Ed. 1990.

10- "*Specification for welding Rods, Electrodes and Filler Metal*", ASME, Part C, July 1998.

11-OP khanna., "*A text book of welding technology*", Dhan pat Rai Publications Ltd2006, p.351

12-Annual Book of ASTMSTANDARDS, "*Standard Practice for Calculation of corrosion Rates and Related Information* ", G102-89,Vol. 03.02, 2004.

Table (1) Chemical Analysis of the used metal 6061- T6

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.
Standard value [9]	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.

Table (2) Chemical composition of the filler metal (Filer wire ER 4043) Al Si_5

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 [10]	4.5-6	<0.6	<0.3	< 0.15	< 0.2	-	< 0.1	-	Rem.

Table (3) Welding parameter of MIG welding

Symbol	Current (Amp.)	Voltage (v.)	Travel speed (mm/s)	Flow rate L/min	No. of passes	Heat input (Joule per mm)	Wire diameter (mm)
B	140	22	110	10	2	1680	1.2
C	150	22	110	10	2	1800	1.2

Table (4) categorizing of specimens

Symbol	Condition
A	A A6061-T6 as received
B	Butt Single V AA 6061- T6 at 70°
C	Butt Double V AA 6061- T6 at 70°

Table (5) corrosion result for all specimens

Symbol	Temperature C°	I_{corr}[µA/cm^2]	E_{corr} [mV]	Corrosion rate (M.p.y) =0.43 i_{corr}
A	25	72.74	-720.9	31.13
	50	67.46	-848	29.085
	75	59.12	-876.0	25.421
B	25	45.6	-735	19.608
	50	40.3	-740	17.329
	75	13.49	-910.8	5.81
C	25	41.5	-760	17.845
	50	21.94	-763.9	9.49
	75	10.48	-817.8	4.506

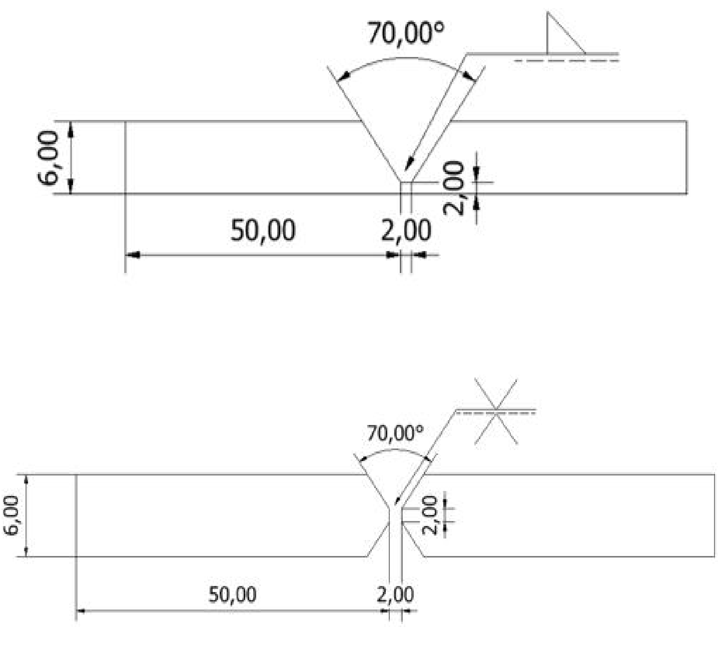
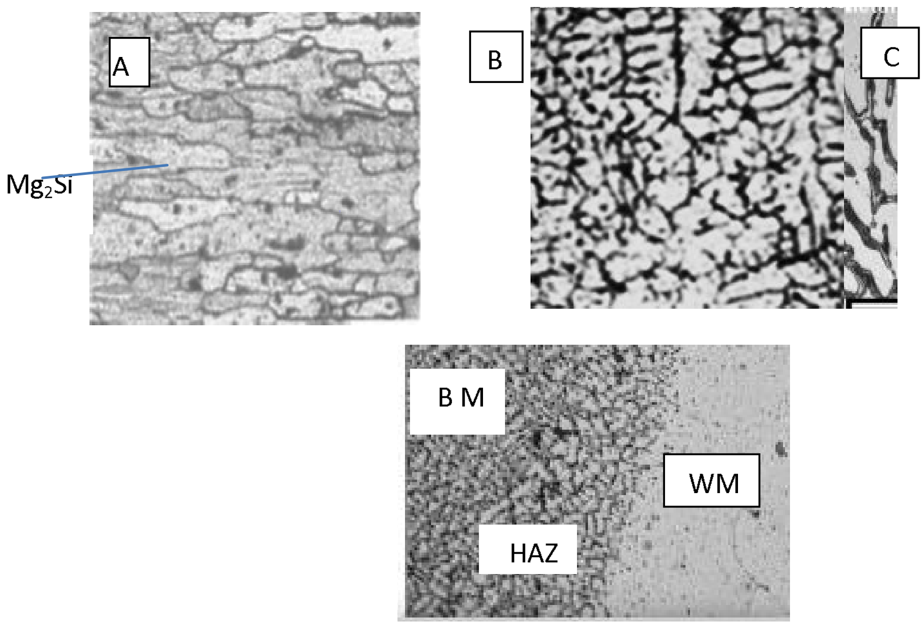


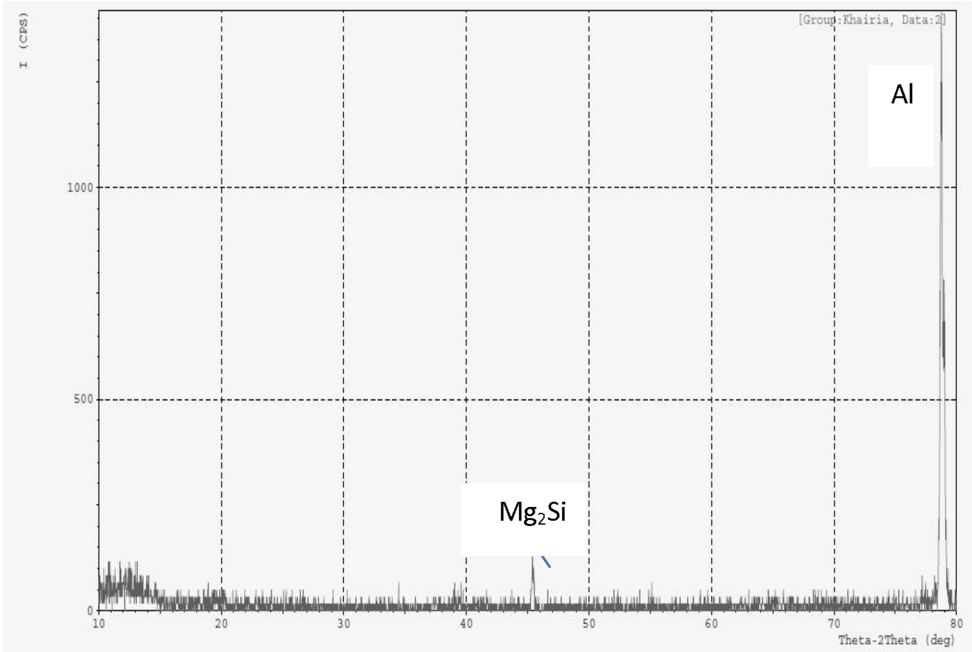
Fig (1) welded joints (All dimensions in mm)

Fig(2) photograph of MIG weld joint



MIG weld zone for specimen (B)

Fig (3) the microstructure of all specimens (40X)



Phase Analysis Graph for Sample (A)

Phase Analysis Graph for Sample (B)

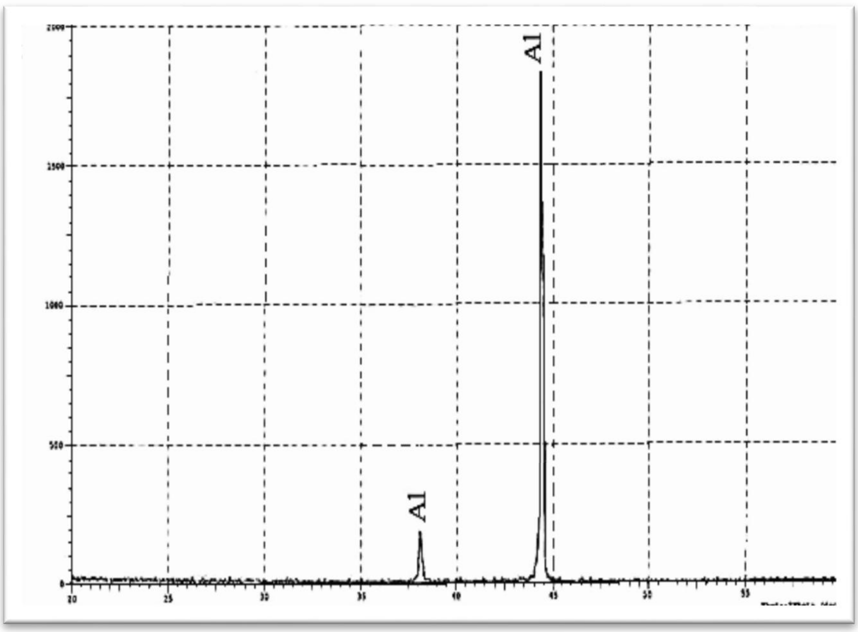


Fig.(4) Phases analysis graphs for specimens (A,B)in Table(2)

Fig(5) The electrochemical corrosion unit

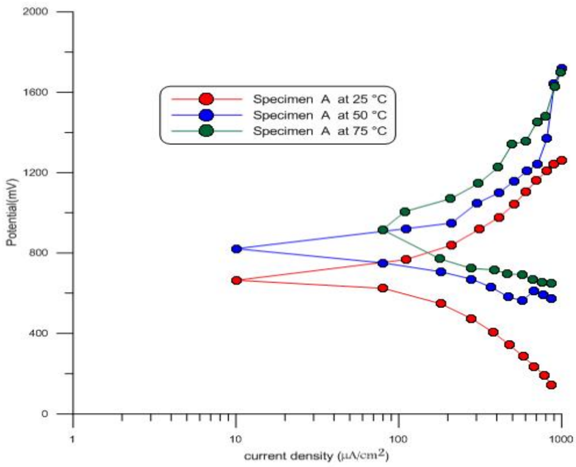


Fig.(6)Electrochemical behavior polarization for specimen(A) at different temperatures.

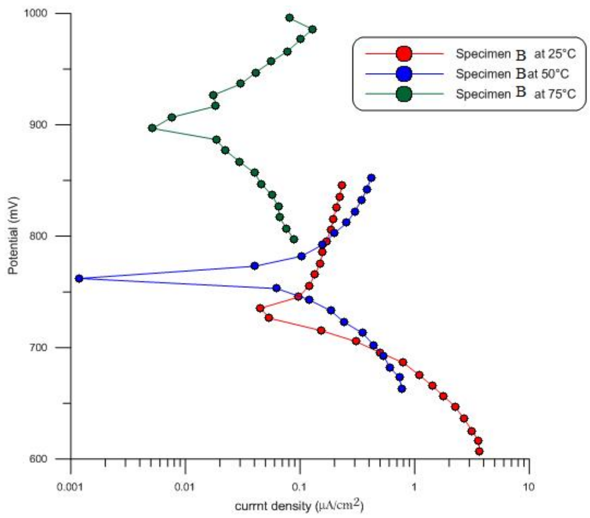


Fig.(7) Electrochemical behavior polarization for specimen(B) at different temperatures.

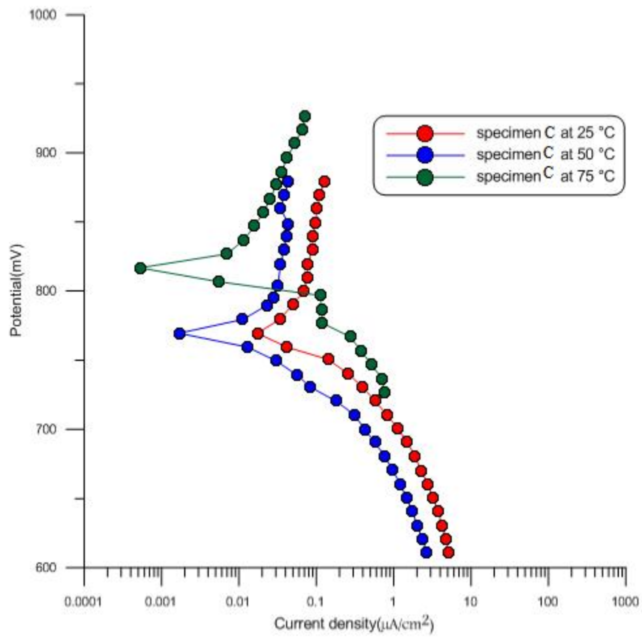


Fig.(8) Electrochemical behavior polarization for specimen(C)at different temperatures.

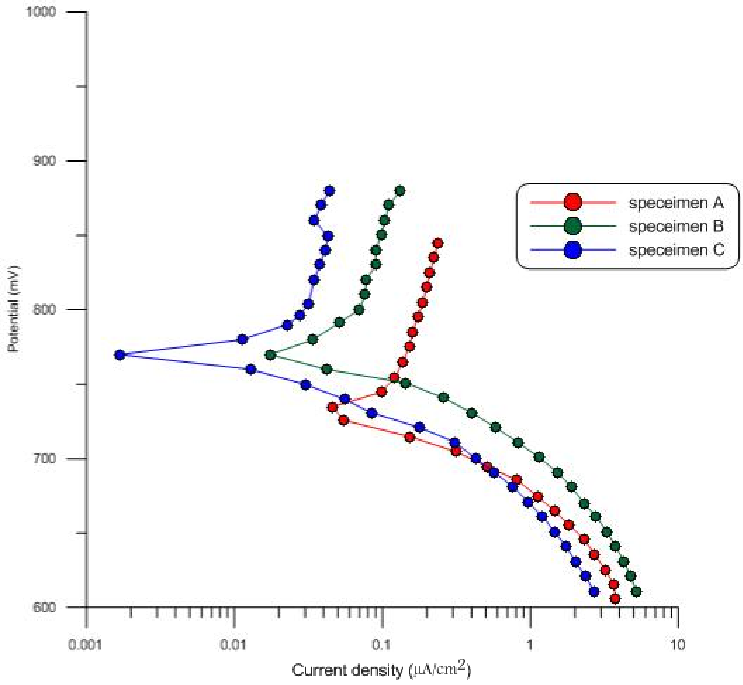


Fig.(9)Electrochemical behavior polarization for all specimens at 25 C°