



## **Study of erosion-corrosion and electrochemical corrosion in some Aluminum alloys (Al 2024T3 and Al 7075T6)**

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Received 16 Feb. 2017; Received in revised form 30 Mar. 2017; Accepted 5 Apr. 2017; Available online 1 Nov. 2017

### **Abstract**

In this research comparative study between the electrochemical corrosion and erosion-corrosion for two high strengthened aluminum alloys (Al 2024T3 and Al7075T6) was investigated. First corrosion test was performed in seawater (3.5%NaCl solution) using a Tafel extrapolation method and cyclic potentiodynamic polarization tests While the second erosion-corrosion test was carried out in slurry solution (1wt% SiO<sub>2</sub> sand in 3.5wt% NaCl solution as the erodent),with varying impact angles (30°, 45° and 90°). It was found that the corrosion rate of Al7075T6 alloy was lower than those of Al2024T3 alloy in case of Tafel extrapolation for polarization test. It was shown that the weight loss rate or erosion- corrosion rate in (gmd) unit for Al7075T6 was lower than that of Al2024T3 at all impact angles during the erosion-corrosion test.

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**Keywords:** Erosion-corrosion; Electrochemical corrosion; Al-alloys; Slurry solution; Impact angle.

### **1. Introduction**

Erosion-corrosion is the increase of corrosion rate and wear rate or attack surface. This phenomena includes the metal removing from the surface as dissolved ions, or it results as solid corrosion products which are mechanically swept from the metal surface [1]. Many types of apparatus and equipments exposed to moving fluids are subject matter to erosion-corrosion. Such as piping systems, mainly bends, elbows and tees, valves, pumps, blowers, propellers, agitators, turbine blades, nozzles, ducts and vapor lines, grinders, mills and equipment subject to spray. Erosion phenomena involves solid particle progress in a fluid stream (gaseous or liquid) which causes material removal due to mechanical effects (wear) and chemical effects (corrosion) [2]. There are many methods or surface treatments techniques to improve the surface resistance to aggressive environments and protect the components or parts from erosion – corrosion damage [3]. Aluminum alloys offer attractive combination of properties for an extensive use in various industries in aerospace, automobiles, railway vehicles, bridges, offshore structure top sides and high speed ships due to their light weight and higher strength to weight ratio. Aluminum alloys of series 2xxx and 7xxx especially Al2024 and Al7075 find wide applications in aircraft structures due to their good properties such as high strength to weight ratio and increasing other properties like stiffness, fatigue

resistance and corrosion resistance due to existence or forming an protective oxide layer which gives corrosion protection of aluminum surface. Aluminum and its alloys can subjected to many types of failure such as wear, corrosion, erosion and erosion-corrosion.

Algahtani *et al.* [4] investigated the erosion resistance of three types of ceramic coatings deposited on 6082 aluminum alloy. These are hard anodized (HA), plasma electrolyte oxidized (PEO) and plasma sprayed ceramic coatings (PSC). They found that the performance of aluminum alloy can be increased with using different surface treatments. PEO coating gave greater erosion resistance comparing to other coatings of HA and PSC. They found also PEO coatings are more dense comparing to HA and PSC coatings and show crystalline Al<sub>2</sub>O<sub>3</sub> structure and higher hardness.

Kazi Kabir and Iqbal Mahmud [5] investigated the electrochemical behavior of stainless steel, brass, and aluminum. A comparative studies in flow effect on the erosion-corrosion and pure corrosion, open circuit potential (OCP) measurements were performed in both quiet and flow conditions in the seawater and sodium carbonate medium to obtain three types of curves for all metal environment combinations. The results showed that increasing OCP indicated that the metals behave in noble behavior while decrease in OCP indicated that the metals expose to corrosion in those environments.

Muna *et al.* [6] studied the corrosion resistance of the friction stir welded joints of Al2024-T3 alloy with using CNC milling machine at different tool rotational speeds and welding speeds. Corrosion current and potential and corrosion rate were determined of base alloy and welded joints in 3.5%NaCl solution at a temperature of 30 °C using potentiostatic polarization measurements. The results showed that the corrosion rates of welded joints were higher than that of base alloy.

Muna and Mohammed [7] studied the erosion –corrosion behavior of aluminum metal composite which involves the (Al–12wt% Si) alloy as matrix phase and 10 wt% SiC particles as reinforcing phase. Erosion-corrosion test was performed in slurry solution which consists of 1wt% SiO<sub>2</sub> sand in 3.5wt% NaCl solution as the erodent with varying angle of impact as (0°, 30°, 45° and 90°). They found that the weight loss rate or rate of corrosion in (gmd) unit at impact angle (0°) was lower than that of other impact angles for the base alloy and composite material. It was shown that the erosion-corrosion rate for composite specimen was less than that of the base alloy. Rana *et al.*[8] studied the effect of adding SiO<sub>2</sub> particles in various percentages (1, 2, 3 wt%) on corrosion behavior of base alloy (Al-Cu-Mg) in 3.5% NaCl solution using polarization method at scan rate 3 mV/ sec. Cyclic polarization measurements were carried out to estimate the pitting corrosion of Al-Cu-Mg composites. The results show the corrosion rate decreased with increasing of SiO<sub>2</sub> % as compared with base alloy. This is due to covering the anodic sites for alloy with passive oxide layer which reduce dissolution of aluminum.

The aim of the present work is to make comparative study between the electrochemical corrosion (pure corrosion) in 3.5% NaCl solution and erosion-corrosion in an erosive- corrosive environments in a slurry media containing sand (1wt%SiO<sub>2</sub>) in 3.5wt% NaCl solution at different impact angles for Al2024 T3 and Al7075 T6 alloys.

## 2. Experimental work

### 2.1 The material used

In this study the materials used were aluminum alloys AA2024T3 and AA7075T6 because of their wide applications such aerospace industry, automotive, building, requiring good corrosion resistance, railroad cars, tank fittings, general structural and high pressure application, etc [9]. The chemical composition of Al-alloy was analyzed in the Specialized Institute for Engineering Industrial /Baghdad as shown in Table 1.

Table 1. Chemical composition for Al2024T3 and Al7075T6.

Element wt%	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Pb	V	Al
2024T3	0.126	0.280	4.37	0.593	1.27	0.013	0.009	0.166	0.016	0.008	0.010	Bal
7075T6	0.053	0.296	1.64	0.010	2.12	0.183	0.002	5.56	0.020	0.008	0.008	Bal

T3: solution heat treatment followed by cold work, HV= 137

T6: solution heat treatment followed by artificial aging, HV=155

### 2.2 Specimens preparation

The specimens were cut in dimensions of (2.0x2.0x0.3) cm for erosion – corrosion test. After cutting, they were ground in sequence on (220, 320, 500, 800, 1000 and 1200) grades of SiC emery paper under running tap water on a hand grinder. Then the specimens were polished, washed and dried with a clean tissue, degreased by immersing them in acetone then dried with paper tissue and held in reserve in glass chamber with a silica gel for one hour. After the specimens were prepared, their microstructures after etching was examined and the weights of specimens were measured using a digital balance (Denver Type) with precision of  $\pm 0.1$  mg.

### 2.3 Erosion-corrosion apparatus

The erosion - corrosion apparatus used in this study is similar to that proposed by Mksim Antonov and Margaret Stack [10]. The principal scheme is shown in Figure 1. A plastic (Perspex) tank is used as a chamber. The Perspex tank has a dimensions of (30) cm in length, (20) cm in height, and (20) cm in width. The slurry corrosive media is delivered directly at high pressure in vertical direction at the specimen face through jet nozzle by a pump sucking the media from plastic tank (chamber) using 1 horse power, single phase electric motor made by Teflon (Chemical Pump). This apparatus was designed and manufactured in accordance with the test apparatus explained in American standard (ASTM G73).

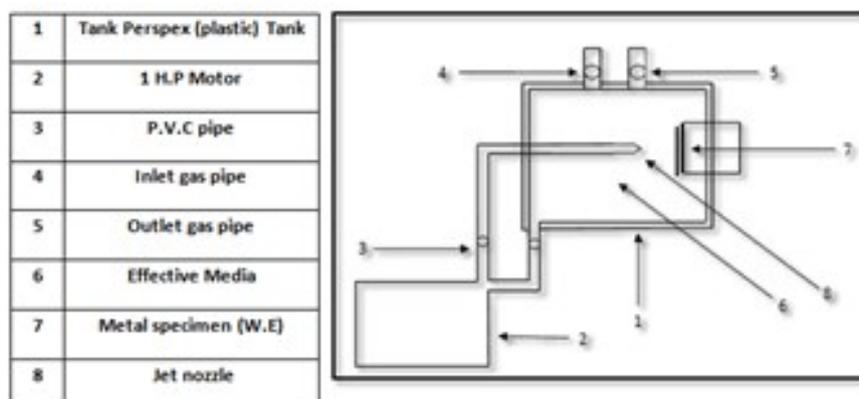
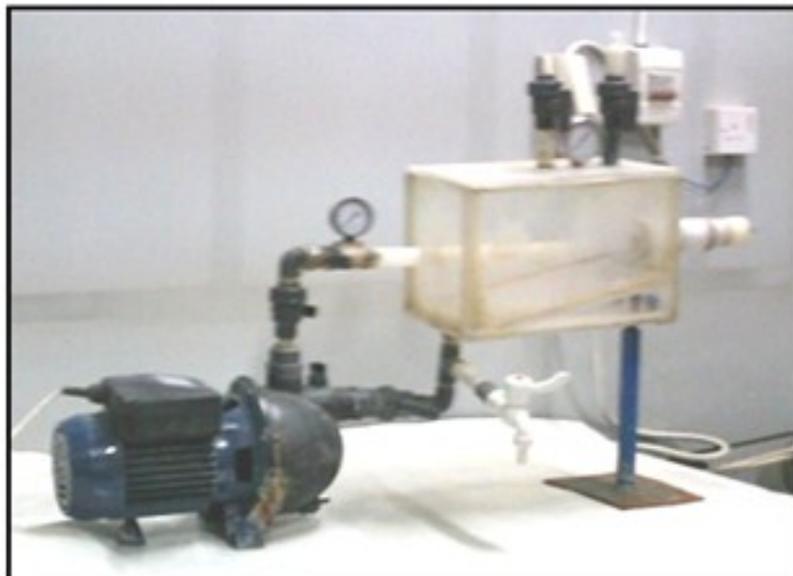


Figure 1. Erosion-corrosion device used in this study.

### 2.4 Weight loss method

Weight loss method is one of the classical methods to find out corrosion rate, and erosion – corrosion rate in different units, but in this section, gmd (gram/meter square\* day) unit is used to measure the above mentioned rates. After filling the chamber of the erosion-corrosion apparatus (as shown in Figure 1) with slurry corrosive medium for erosion-corrosion test and this media is listed in Table 2. Corrosive

medium is injected toward the specimen surface for 75 min in erosion – corrosion test, the flow rate is 36 L/min and medium injection pressure is 1bar. Then the sample is exposed to the slurry medium and then is weighed after every 15 min until reach to 75min of exposure time. The weighing is carried out after the specimens are cleaned with distilled water and a brush, and then with acetone or alcohol. Drying of the specimens is carried out using drying paper and specimens driers. The erosion – corrosion rate with slurry was found to get results in gmd unit [1].

Table 2. Summary the corrosive environment details used in this study.

Test	Medium type	Corrosive environment details
1	Electrochemical corrosion test	<ul style="list-style-type: none"> <li>• 3.5wt% NaCl solution</li> <li>• Temperature: 25 °C</li> <li>• pH: Sea Water (7.4)</li> </ul>
2	Erosion-Corrosion with slurry test	<ul style="list-style-type: none"> <li>• 3.5wt% NaCl solution with 1wt% SiO<sub>2</sub> sand.</li> <li>Particles size: over 355-53 μm</li> <li>• flow rate : 36 L / min</li> <li>• pressure: 1 bar</li> <li>• Temperature: 25°C</li> <li>• pH : Sea Water and with silica Sand (7.4)</li> <li>• Impact angle constant : 30°, 45°, 90°</li> </ul>

### 2.5 Erosion-corrosion media

The erosion-corrosion test was carried out in slurry media which consists of silica sand particles of 1wt% SiO<sub>2</sub> concentration and sea water. The sea water was used as a corrosion medium and a medium to drive sand particles toward the target. Quantity of water used was restricted to the capacity of holding tank and specified to be as six liters. The percentage of sand particles added to the water depends upon concentration required. The sand particles size remained constant (over 355-53 μm). The same thing goes for the distance between ejector nozzles and target. A different impact angle of 30°, 45° and 90° were used for all specimens. The test specimens were eroded under the same constant pressure of compressed air [10].

### 2.6 Electrochemical corrosion test

For electrochemical corrosion tests small specimens were prepared with dimensions (1.5x1.5x 0.3) cm according to ASTM (G71-31) specifications and then each specimen with exposed area (1x1cm<sup>2</sup>) was immersed in the 3.5% NaCl solution with PH of 7.4. Cell current readings were taken during a short, slow sweep of the potential. The sweep was taken from (-1000 to + 1000) mV relative to (OCP). Scan rate defines the speed of the potential sweep in mV/sec and it was taken 10 mV/sec. The tests were performed by using a WENKING Mlab multi channels potentiostat and SCI-Mlab corrosion measuring system from Bank Elektroniks-Intelligent control GmbH, Germany 2007, as shown in Figure 2. In this research the Al2024T3 or Al7075T6 alloy was used as working electrode (WE). The reference electrode was standard hydrogen electrode (S.H.E). Auxiliary electrode used in the electrochemical cell was platinum type. In case of the cyclic polarization test the potential range was -250, +1500 mV of the open circuit potential with using 5mV /sec as scan rate.

All samples or specimens which were prepared for corrosion test were immersed in laboratory sodium chloride solution of 3.5wt% NaCl to find the parameters of corrosion, such as the potential of corrosion (E<sub>corr</sub>) and the current of corrosion (I<sub>corr</sub>) at each time. The corrosion rate was calculated according to Tafel equation as shown in equation (1) [11].

$$C.R(\text{mpy})=0.13 \cdot I_{\text{corr}} \cdot \text{eq.wt}/\rho \quad (1)$$

where: (mpy)= corrosion rate (mils-inch per year) or (0.0254mm/year). I<sub>corr</sub> = corrosion current density (μA/cm<sup>2</sup>). Eq.wt = equivalent weight in grams / equivalent of the corroding species. ρ= density of the corroding specimens (g/cm<sup>3</sup>).

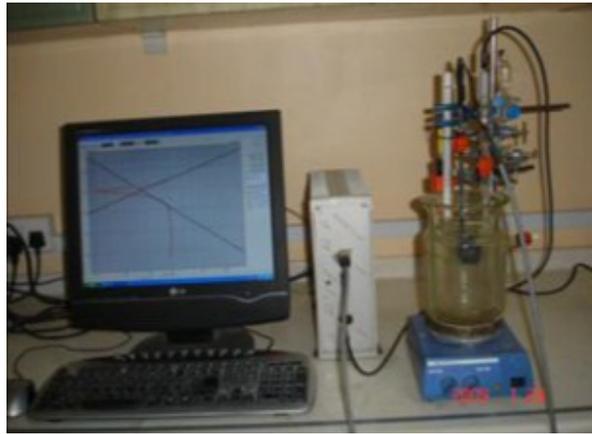


Figure 2. The unit used for electrochemical corrosion.

### 2.7 Microstructure examination

Optical microscope was used to examine the microstructure of samples of two Al-alloys before and after corrosion. Wet grinding was made with emery paper of SiC in various grades of 320,500, 800 and 1000 after that polishing process was made using 0.5  $\mu\text{m}$  diamond paste with special cloth and lubricant. Etching process was carried out on the samples before corrosion test by using Killer's solution (95ml  $\text{H}_2\text{O}$ , 2.5 ml  $\text{HNO}_3$ , 1.5ml  $\text{HCl}$ , 1.0 ml  $\text{HF}$ ) and then the samples were washed and dried.

## 3. Results and discussion

### 3.1 Erosion-corrosion results

Figures 3, 4, and 5 show the erosion-corrosion behavior of Al2024T3 and Al7075T6 at different impact angles of 30°, 45°, and 90° respectively in slurry solution (1 wt% silica in 3.5% sodium chloride solution). It was observed that loss in weight or erosion-corrosion (E-C) rate in gmd unit increases with exposure time to solution until it reaches to maximum value afterward it reduces continuously to lower values for longer period of time (75min). This case occurs because of the silica sand slurry which erode the soft metal surface layer. It can be explain that the erosion- corrosion with slurry produces the greatest weight loss rate which comes from two special effects; one is a mechanical resultant from high velocity of corrosive solution with slurry that produce cavitation, impingement, erosion and corrosion. The other effect is electrochemical one which is happened by the reaction between the corrosive solution and the specimen. It was observed that the erosion- corrosion behavior was similar for the two Al-alloys in case of impact angles 30° and 45°. While at impact angle 90° the E-C rate increases rapidly with increasing exposure time reaching to 75min. These results are similar in erosion-corrosion behavior with those of researchers Adel and Anees in [12]. They found that the erosion-corrosion rate in (gmd) of low carbon steel in saline water raised with time, concentration of sand in solution and angle of impact. Figure 6 shows the effect of impact angles on E-C rate for two Al-alloys. It had shown that loss in weight or E-C rate of Al7075T6 was lower than the Al2024T3 for all impact angles. This is due to higher hardness of Al7075T6 which was HV155 while it was HV137 for Al2024T3.

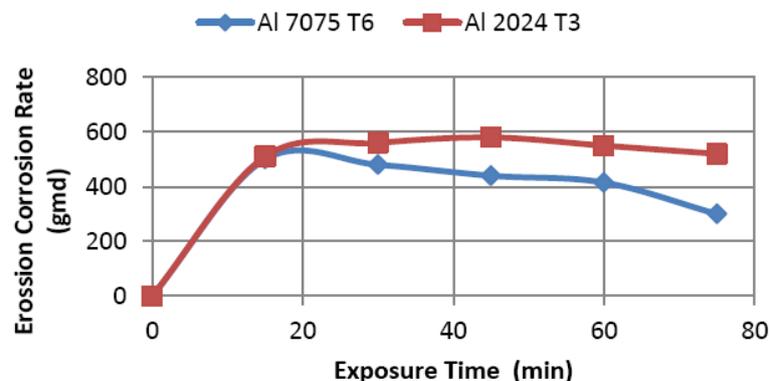


Figure 3. Erosion-corrosion rate of two alloys at impact angle 30°.

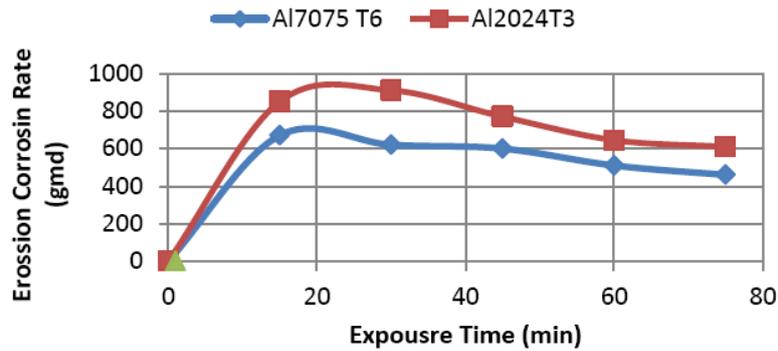


Figure 4. Erosion-corrosion rate of two alloys at impact angle 45°.

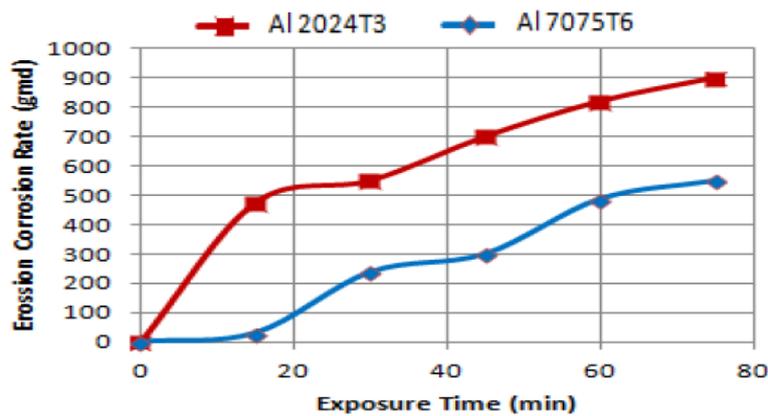


Figure 5. Erosion-corrosion rate of two Al-alloys at impact angle 90°.

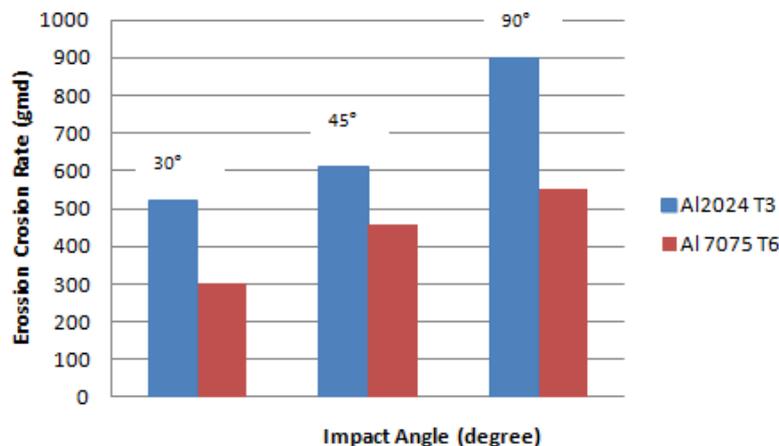


Figure 6. Impact angle effect on the rate of erosion-corrosion for two Al-alloys.

### 3.2 Electrochemical corrosion results

The polarization curves for two alloys Al2024T3 and Al7075T6 in 3.5% NaCl solution at ambient temperature are shown in Figures 7 and 8 respectively. It was seen that the behavior of corrosion in cathodic and anodic polarization curves are similar for two Al-alloys but the Al7075T6 has corrosion rate lower than the Al 2024T3. This is due to development of inactive or passive alumina oxide layer or film on the surface of both alloys but this film was more stable and immune to attack the alloy Al7075T6 which exhibited higher corrosion resistance. The protective passivating oxide film forms rapidly on the surface of aluminum alloy and acts as an obstruction to metal dissolution, and decreasing the rate of corrosion. Tafel extrapolation method was used to find the corrosion parameters and rates of corrosion which are summarized in Table 3. The average potentials of corrosion ( $E_{corr}$ ) can be determined from these polarization curves as -865.2 mV, -781 mV for Al7075T6 and Al 2024T3 respectively. The corrosion potentials resulted from the polarization curves are significantly lower than those obtained

from the open circuit potentials measurements. The corrosion current densities and corrosion rates for investigated Al-alloys were obtained from the Tafel extrapolation method using both cathodic and anodic kinds of the polarization curves.

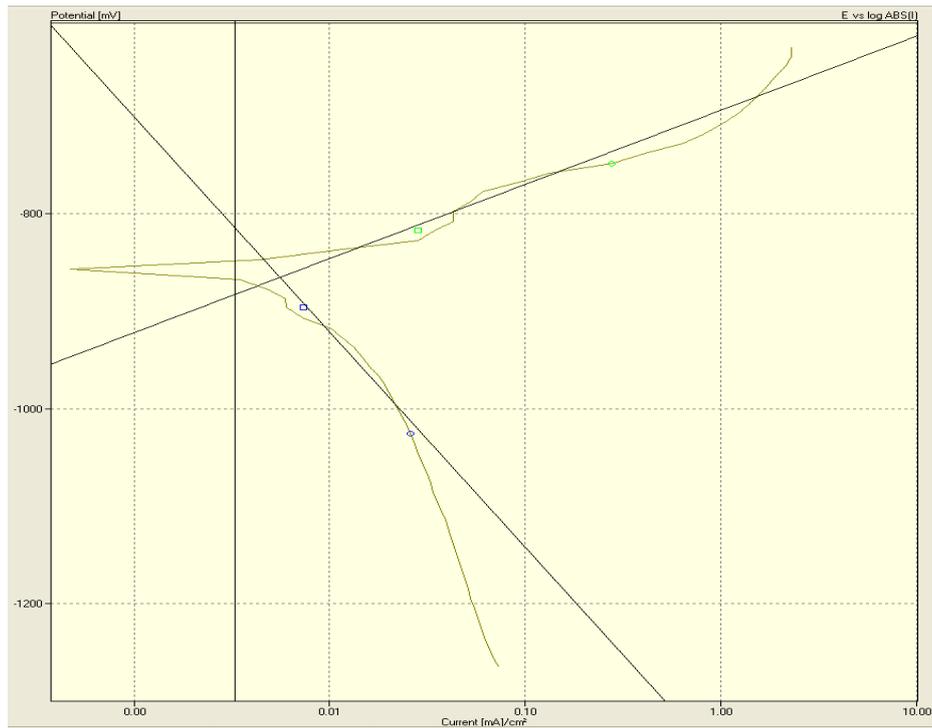


Figure 7. Tafel polarization curve (relation between current density ( $\text{mA}/\text{cm}^2$ ) and potential (mV)) for Al 7075T6 in 3.5% NaCl solution.

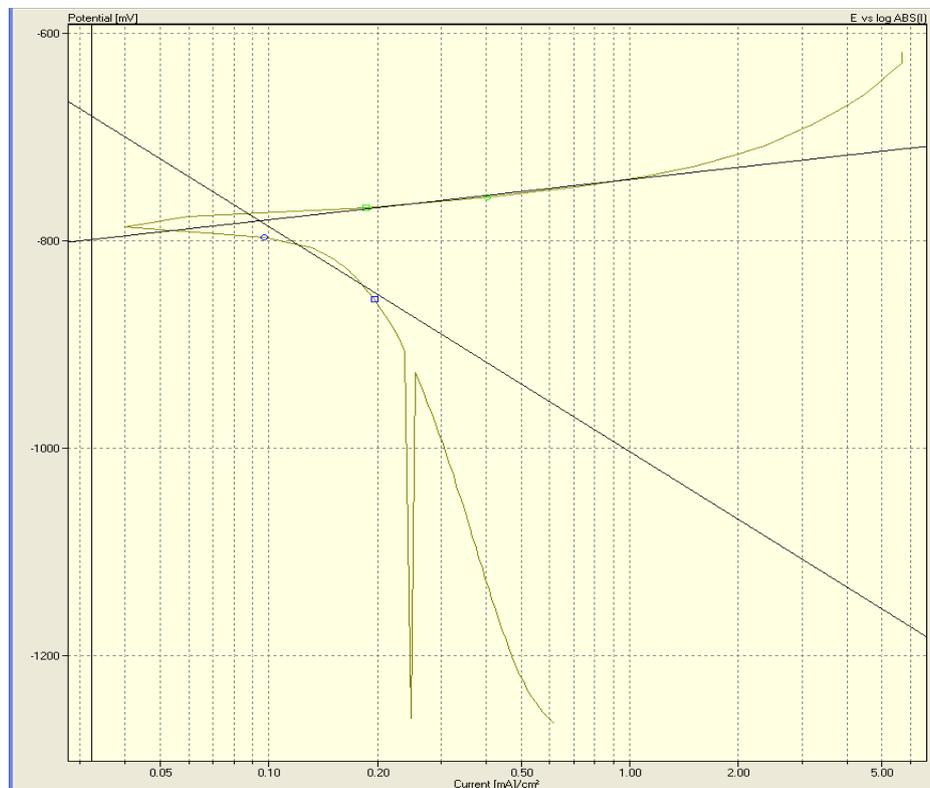


Figure 8. Tafel polarization curve (relation between current density ( $\text{mA}/\text{cm}^2$ ) and potential (mV)) for Al 2024T3 in 3.5% NaCl solution.

Table 3. Corrosion parameters of two Al- alloys in 3.5% NaCl solution.

Sample	OCP mV	E <sub>corr.</sub> mV	I <sub>corr.</sub> $\mu\text{A}/\text{cm}^2$	$\beta_c$ mV/Dec	$\beta_a$ mV/Dec	C.R(mpy)
7075T6	-910	-865.2	5.58	-221	76.2	2.792
2024T3	-820	-781	94.1	-216.8	38.9	43.67

It was seen that the current density  $I_{\text{corr}}$  of Al2024T3 was higher than that of Al7075T6. This is due to existence of alloying elements such as Cu, Mg, Zn as intermetallic of Al-Cu, Mg-Zn compound or 2<sup>nd</sup> precipitates of  $\text{Al}_2\text{Cu}$  ( $\theta$ ) and  $\text{Mg}_2\text{Zn}$  ( $\beta$ ) in Al 2024T3 and Al7075T6 respectively which promote the oxygen reduction of cathodic reaction and then accelerate corrosion process [13]. As results the inactive or “passive”  $\text{Al}_2\text{O}_3$  film created on the intermetallic particles become less protective than those formed on aluminum matrix [13, 14]. These particles act as cathodic site against the aluminum matrix which leads to dissolution of the protective oxide film and enhancing pitting corrosion. Many researchers are confirmed the importance of intermetallic compound or second phase particles as initiation sites for corrosion [15, 16].

Figures 9 and 10 show the cyclic polarization curves for Al2024T3 and Al7075T6 to know the pitting susceptibility in 3.5%NaCl solution. These curves indicate no pitting occurred for two Al-alloys. This is due to development of stable alumina oxide film during the frontward scan on the alloy surfaces, also the disappearance of hysteresis loop from the anodic curve and good pitting resistance and passivity of oxide film on surface are characterized of two Al-alloys.

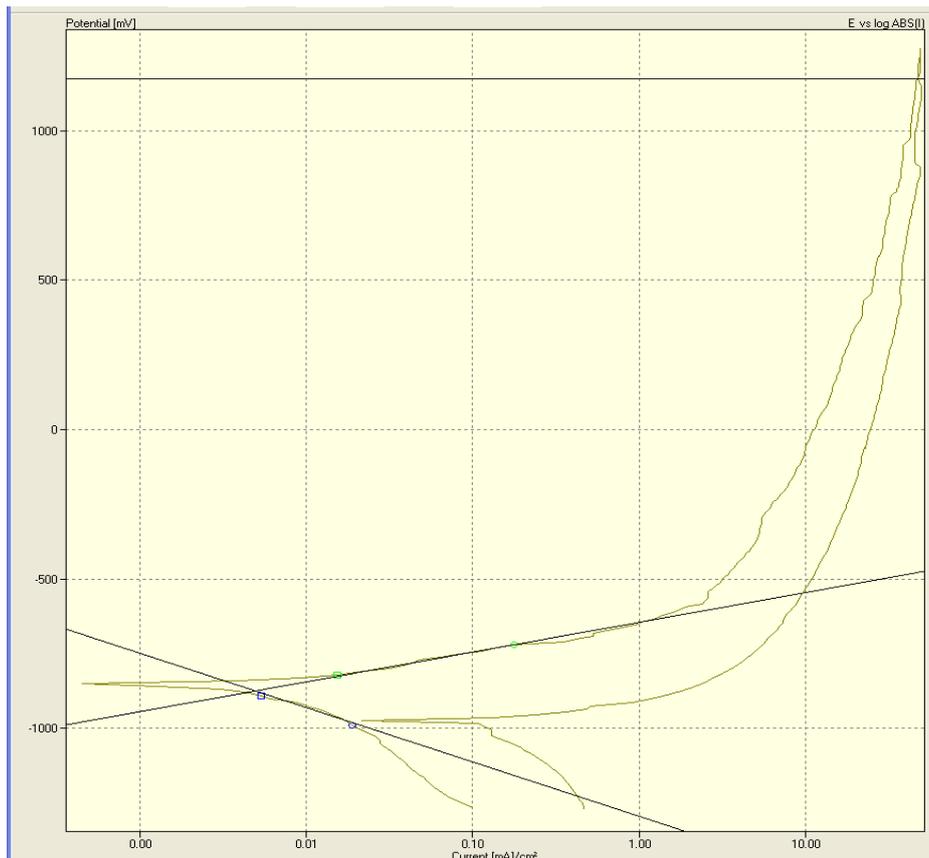


Figure 9. Cyclic polarization curve (relation between current density ( $\text{mA}/\text{cm}^2$ ) and potential (mV)) for Al 7075T6 in 3.5% NaCl solution.

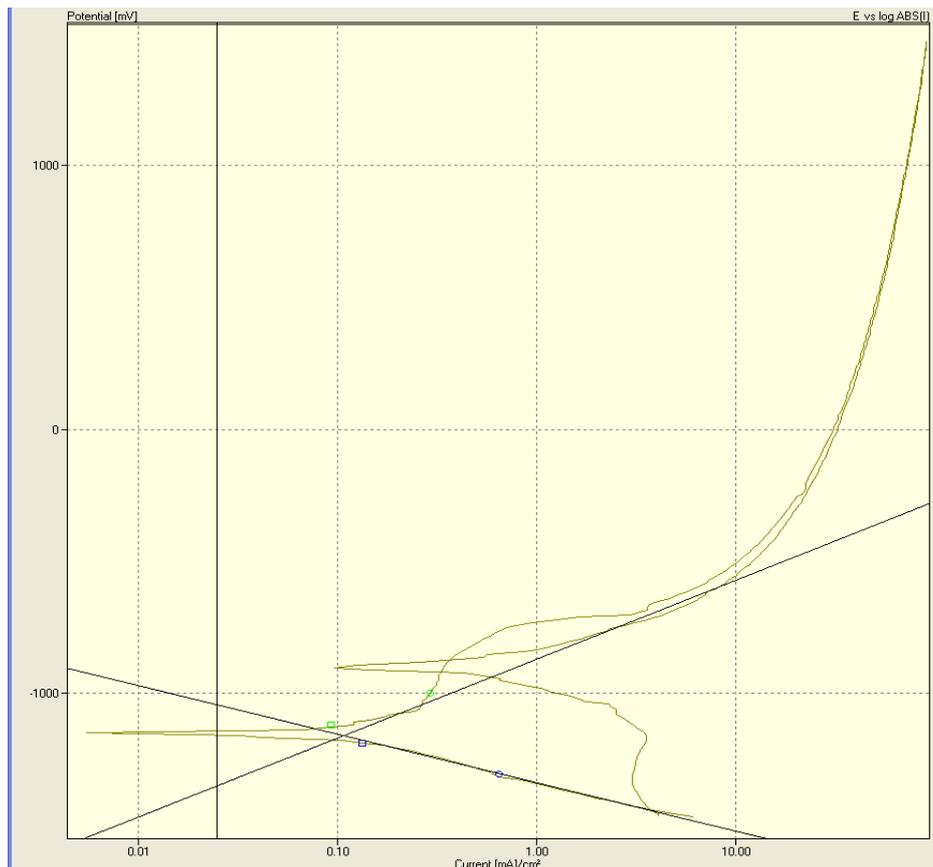


Figure 10. Cyclic polarization curve (relation between current density ( $\text{mA}/\text{cm}^2$ ) and potential (mV)) for Al 2024T3 in 3.5% NaCl solution.

### 3.3 Micrographs after corrosion

Figure 11 shows the microstructure of Al2024T3 and Al7075T6 alloys before corrosion. It consists of the grains of  $\alpha$ -Al phase as matrix and fine precipitates distributed in the structure. Figure 12 shows the micrographs of Al2024T3 and Al7075T6 surfaces after erosion –corrosion test in slurry solution. It contains marks like horse-shoe areas that are dark, distinguishing and tilting toward flow direction of the slurry medium. This result is in agreement with that shown by researchers Stephen M. McIntyre *et al.* [17], Muna and Mohammed [18]. They observed with the erosion-corrosion test, a horse shoe shaped and comet tail pitting damage.

Figure 13 shows the micrographs of Al2024T3 and Al7075T6 after corrosion test in 3.5% NaCl solution, it was observed that a very small and shallow pits form on the surface of Al 2024T3 alloy while the Al7075T6 alloy there is no pits and some corrosion products appear on alloy surface.

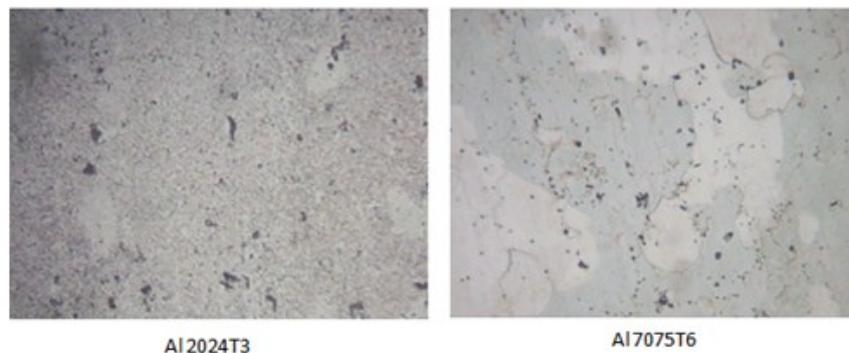


Figure 11. Microstructure of two Al-alloys before corrosion at 125X.

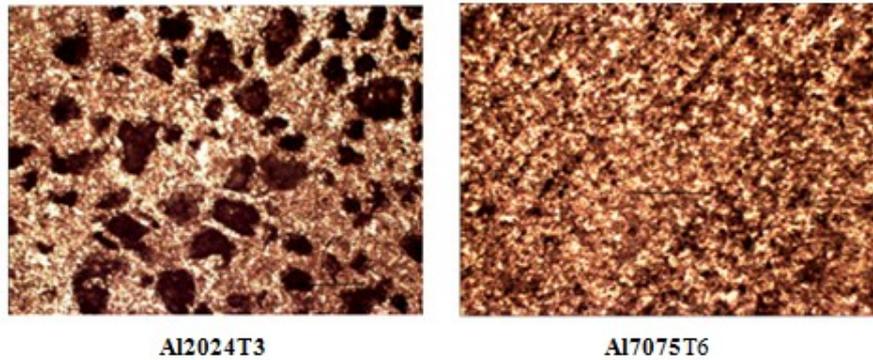


Figure 12. Micrograph pictures of two Al-alloys after erosion-corrosion test at impact angle 90° at 100 X.

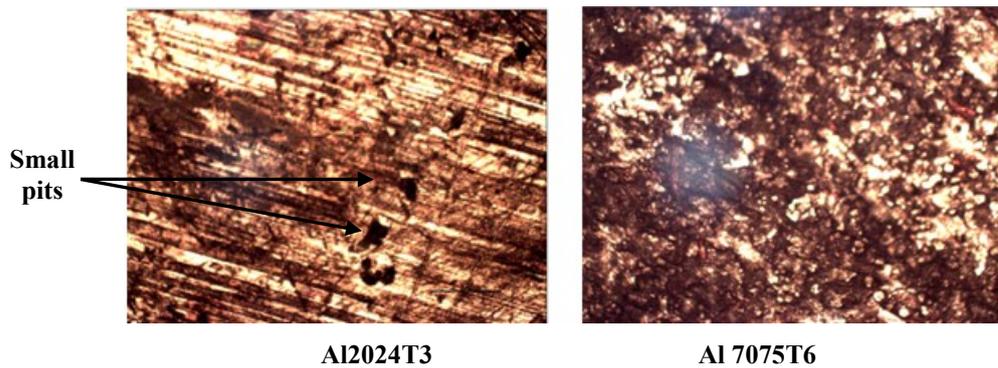


Figure 13. Micrograph pictures after corrosion test in 3.5% NaCl solution at 100 X.

#### 4. Conclusions

- 1- From Tafel extrapolation analysis method for both cathodic and anodic polarization curves, it was found that the corrosion rate of Al7075T6 alloy was lower than Al2024T3 alloy in 3.5%NaCl solution.
- 2- The rate of erosion-corrosion in slurry solution increases with exposure time up to reach a maximum value and then it decreases at longer exposure times in case of impact angles 30° and 46°.
- 3- The erosion-corrosion rate increases with increasing impact angle from 30° to 90° for two Al-alloys.
- 4- It was shown that the loss in weight or rate of erosion-corrosion of Al7075T6 alloy was lower than Al2024T3 alloy at all impact angles 30°, 46° and 90°.
- 5- The two Al-alloys exhibit good pitting resistance in 3.5% NaCl solution, also the hysteresis loop disappears due to the passivity of oxide film on surface of two Al-alloys.

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2013-2017 she had published many papers in Nano Technology and Nano science field such as Nanocomposites and Nanocoating and also in smart materials such as copper based shape memory alloys.

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