

## EFFECT OF ANNEALING PROCESS ON THE CORROSION RESISTANCE OF ALUMINUM ALLOY 2024-T3

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### ABSTRACT

The effect of annealing process on corrosion resistance for aluminum (2024-T3) alloy is investigated. Samples of this alloy had been manufactured with dimensions (1.5\*1.5\*0.3) cm according to ASTM specifications. The annealing process applied by heating the metal in three deferent times; 270°C for two hours, 400°C for half hour and 350°C for one hour. After that the X-Ray Diffraction test has been done in order to know the phases resulted. The electrochemical corrosion test has been done by fixing the potential of the cell and changing it, the potential is chosen depending on open circle and comparing it with the standard metal potential of electrochemical series then adding 100 volt to show the cathode and anode behavior of metal, it had been found that the corrosion average resistance affected by temperature degree and time of the process, it had been noticed that increasing annealing temperature the corrosion resistance of alloy decreased, specially at 400°C, the heat treatment at the temperature 270°C was the best.

**KEYWORDS:** Annealing, Corrosion, Aluminum Alloy.

### 2024- T3

3 . 2 . . . . 1 . . . .  
/ - 1  
- / 2  
- / 3

2024 T3

.ASTM

(1.5 \*1.5 \*0.3) cm

350°C

400°C

270°C

( X-Ray )

## INTRODUCTION

Annealing is a heat treatment used for changing the properties like rigidity and strength by heating the metal to a specified temperature degree and then cooling it slowly, the object of annealing is realizing the ductility and softness for metal and removing all internal stresses and making it homogeneous by fining the grains and improving cold forming properties. Annealing had been done by spreading atoms in solid case until stability reached, where the heat takes place in spreading by providing the required energy for breaking the bounds, the atoms movement has an effect on the redistribution and breaking the extract existed in metal caused by forming that makes the plastic forming process more easy where the annealing role is decreasing the energy required for forming and removing the internal stresses which could be removed in room temperature degree for several metal types or could be done quickly by heating to a high temperature degree. The annealing could be done in three stages the first called recovering by removing the linear crystal defects and internal stress which is caused by these defects, this stage cover most of annealing stages. The second stage is recrystallization where the new crystals created to take the place of deformed crystals by internal stresses resulted from forming process. Third stage is resulted from the higher temperature than recrystallizing temperature degree (RT) and run out time where the grains grows to course grains which affect the microscopic instruction of which decrease the mechanical properties. The (2024-T3) aluminum alloy considered one from the high strength alloys which is used in many engineering applications which needs high strength like gears, rotating shafts, pins, valves, bolts, nuts and other parts of aircrafts and computer structures, this alloy distinguished by good corrosion resistance and could be improved by heat treatments (T8, T6) which could give more strength and stress and galvanic corrosion resistance.

**Ming Liu, 2008**, studied the corrosion of commercial die-cast Mg–Al alloys was elucidated by a study, of the corrosion in 3% NaCl, of (i) high-pressure die-cast (HPDC) model Mg–Al alloys, (ii) low-purity Mg, (iii) high-purity (HP) Mg and (iv) HP Mg heat treated at 550 °C. **In-Joon Son, 2009**, studied the effect of equal-channel angular pressing (ECAP) on the pitting corrosion resistance of anodized Al–Cu alloy was investigated by electrochemical techniques in a solution containing 0.2 mol/l AlCl<sub>3</sub> and also by surface analysis. The improvement of pitting corrosion resistance of anodized Al–Cu alloy processed by ECAP appears to be attributed to a decrease in the size of precipitates, which act as origins of pitting corrosion. **Mohammad Tajally, 2009**, presented a research reports comparative analysis of effects of cold working (CW) and annealing on tensile and impact-toughness behavior of 7075 Al alloy. **Rahman A. Hussain, 2002**. Studied the effect of different quenching mediums on hardness of (Al –Cu) alloy, the results show that the hardness changed according to type and cooling rate and this is due to the types and amounts of solid solution resulting from cooling process. **C. Scha'fer, et. Al**. Hence, prove that varying the heating rate the relative extent of various physical mechanisms (recrystallization, recovery, precipitation) can be strongly influenced. **Srihari Kurukuri** shows that on warm forming, three different aluminum alloys: Al–Mg alloy (AA5754) and Al–Mg–Si alloys (AA 6016 and AA 6061) used in the automotive industry are considered. In the stretch forming with intermediate heat treatments, aerospace Al–Cu alloy (AA 2024) is considered. In non-heat treatable Al–Mg alloys, hardening is mainly due to the presence of solute atoms in solid solution and in heat treatable Al–Mg–Si and Al–Cu alloys, strengthening is determined by precipitates formed during ageing treatment..

**K. van der Walde et.al** (2005) performed quantitative fractography on forty 2024-T3 sheet aluminum fatigue specimens. It was found that over half of the specimens analyzed had two or more crack-nucleating pits. The number of nucleating pits per specimen was found to be positively correlated with stress level and an interactive effect with corrosion exposure duration was observed. From the fatigue modeling efforts it is concluded that increased accuracy can be achieved by

incorporating multiple crack effects, particularly at higher stress levels where consistently un-conservative life predictions can be avoided.

**Al.Th. Kermanidis et.al (2005)** prepared 2024 T351 Aluminum alloy in bare, sheet form of 1.6 mm nominal thickness. Machining of the specimens was made according to the specifications ASTM E 466-82 for the fatigue, ASTM E 647-93 for the fatigue crack growth and ASTM E 561-94 for the fracture toughness specimens. The effect of 36 h exposure to exfoliation corrosion solution of bare 2024 T351 aluminum specimens on the fatigue life of the specimens showed that the corrosion attack results in a significant drop of the materials fatigue life . Metallographic corrosion characterization of specimens exposed to 17 exfoliation corrosion solutions for 24 h showed that the presence of corrosion pitting and inter-granular corrosion facilitates essentially the onset of fatigue cracks and, hence, reduces the fatigue life of the corroded specimens appreciably.

In this research an experimental test had been applied to explain the effect of annealing on corrosion resistance for aluminum (2024-T3) alloy.

## **EXPERIMENTAL PART**

### **1-Metal Selection**

Aluminum 2024-T3 alloy selected because it is used in many engineering applications like aircraft parts, the chemical analysis of it explained in **Table 1**.

### **2- Preparation of Test Specimens**

The specimens are prepared from alloy sheets with (1.5\*1.5\*0.3) cm according to ASTM standard specifications to apply the corrosion test experiment.

### **3- Specimens Classification**

After completing the preparation of specimens, it is classified as in **Table 2**.

### **4- Heat Treatments**

The annealing had been done for all specimen groups in **Table 2** where it is included heating to the mentioned temperatures and period of time.

### **5- Tests**

**A- X-Ray Diffraction Test;** applied on specimens mentioned in **Table 2** by using spectrometer, the results shown in **Table 3**.

### **B- Corrosion Test:**

Electrochemical corrosion test had been done on all specimen in **Table 2** where the specimens represent the positive pole from a platinum in seawater solution as an electrolyte solution where the potential of cell fixed by open circuit (**Sami et al, 2005**). The result's value compared with the potential standard of the metal in electrochemical series, the potential had been increased 100 volt to show the cathode and anode behavior for metal after current passing through it, **Figure 1** shows a picture of electrochemical cell.

## **RESULTS AND DISCUSSION**

### **1- Results of electrochemical corrosion**

The microstructure of the alloy specimens is shown in **Figure 2**. Results of corrosion of alloy in different annealing temperatures are shown in **Table 4** and **Figure 3** shows the relation between current intensity and potential of electrochemical cell.

The aluminum (2024-T3) alloy considered one from high strength alloys therefore it is used in many engineering applications like aircraft structures, so the applications of this alloy make it specified with specific properties such as hardness and strength in addition to corrosion resistance so this alloy has to be treated to improve its properties. The improvement may be by cold working or treated by isothermal processing. In this research annealing was the heat treating process applied to develop the corrosion resistance of this alloy. The results of electrochemical corrosion test show that the heating to (270°C) for two hours gave high corrosion resistance compared with the other tests, and this is because of the long period of time for heating which allows the alloy to take sufficient time for all phases to precipitate then gave the alloy a good mechanical and physical properties and this means a good corrosion resistance.

## **CONCLUSIONS**

- 1- By increasing annealing temperature, the corrosion resistance of alloy decreased specially at the 400°C.
- 2- The original alloy without heat treatment gave good corrosion resistance.
- 3- Heat treatment at 270°C was the best temperature.

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**Table 1** Chemical analysis of used alloy

Elements	Cu	Mg	Mn	Fe	Si	Zn	Cr	Ti	Al Rem
Actual	4.4	1.5	0.6	0.3	0.4	0.1	0.05	0	92.6
Standard	3.8-4.9	1.2-1.8	0.30-0.9	0-0.50	0-0.50	0-0.25	0-0.1	0-0.15	

**Table 2** classification test specimens

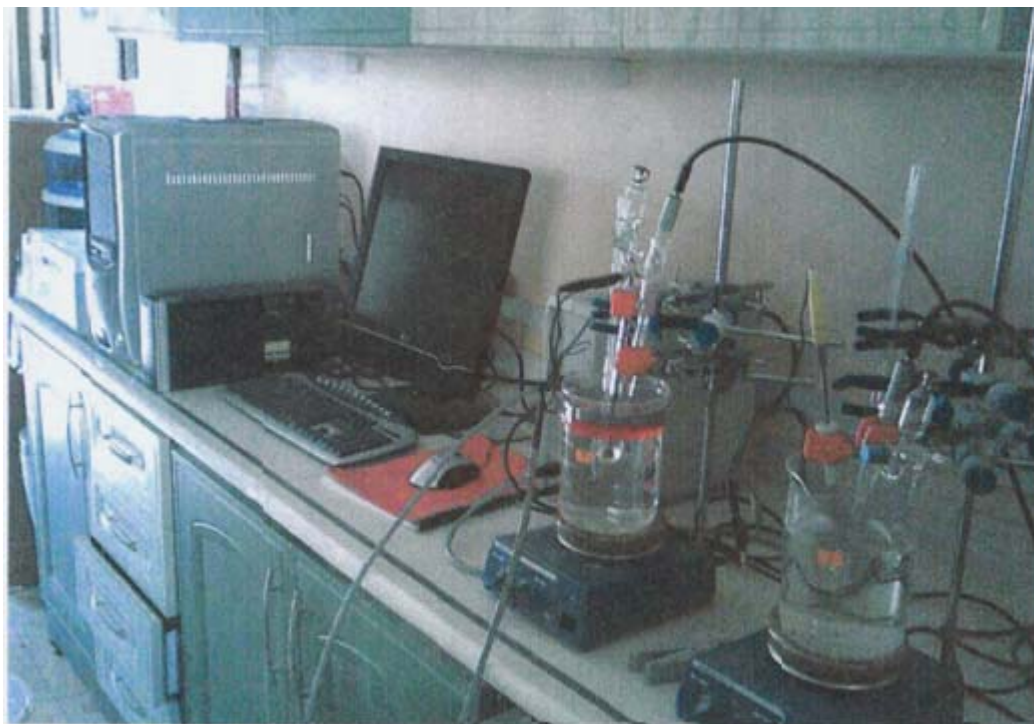
The case	Specimen symbol
metal without heat treatment	A
metal treated to 400°C for one hour	B
metal treated to 350°C for half an hour	C
metal treated to 270°C for two hours	D

**Table 3** Phases resulted from annealing process

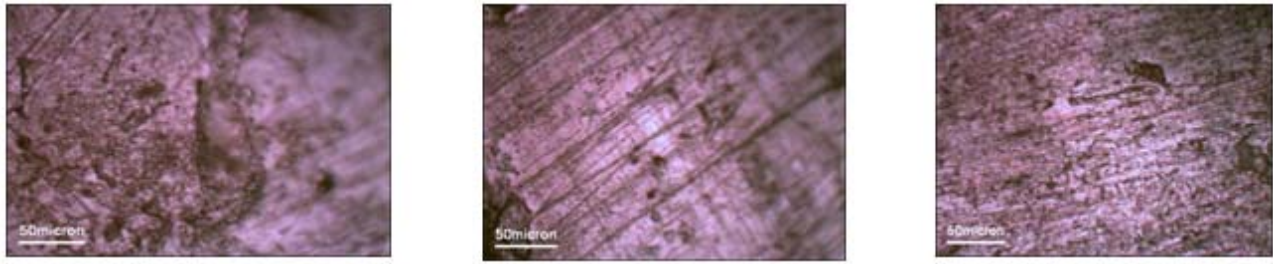
Specimen symbol	The phase
B	AlCu+Al <sub>4</sub> Cu <sub>9</sub>
C	AlCu <sub>4</sub> +AlCu <sub>3</sub>
D	AlCu+AlCu <sub>4</sub>

**Table 4** Results of corrosion alloy in different annealing temperature.

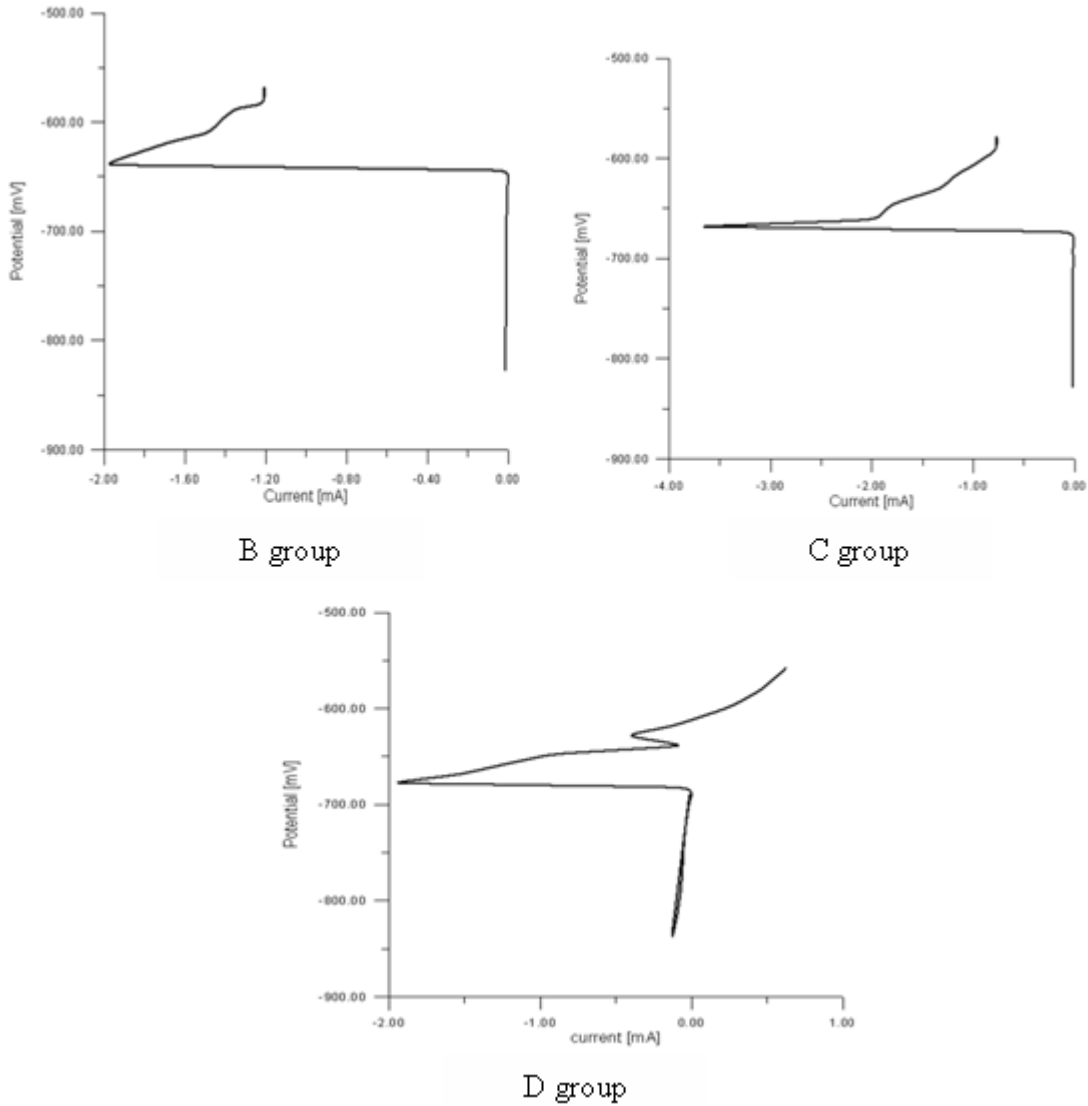
Specimen symbol	I Corr. m A/cm <sup>2</sup>	E Corr. m v	C.R.
A	8.35	-636.9	3.674
B	549.43	-648	197.5549
C	656.32	-667.7	272.2176
D	14.42	-686.5	6.2006



**Figure 1** The electrochemical cell.



(B-group) (C-group) (D-group)  
**Figure 2** Pictures of electrochemical corrosion for different annealing temperatures.



**Figure 3** Relation between current intensity and potential cell.