

# CORROSION BEHAVIOR OF THE 8090-T851 ALUMINUM ALLOY

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## الملخص

تعد سبائك الالومنيوم - ليثيوم من البدائل المفضلة لتطوير طائرات الوزن الخفيف ذات الكفاءة في استهلاك الوقود بالمقارنة بسبائك الالومنيوم التقليدية. لقد تم تقييم قدرة مقاومة التآكل لسبيكة الالومنيوم - ليثيوم المتقدمة 8090 عند اقصى تعتيق (T851) من خلال قياس نقص الوزن ومعدل التآكل في بيئات تغطي مدى شامل من تركيز أيون الهيدروجين (الرقم الهيدروجيني) في المحلول الحامضي، من الرقم الهيدروجيني 1 إلى 5 (pH1-pH5). أظهرت الاختبارات (طبقاً للمواصفة ASTM G-31) أنه أثناء فترة الغمر لمدة ثلاث أسابيع حدث نقص في وزن السبيكة في جميع المحاليل الحامضية. ودلت النتائج على أنه كلما زادت الشدة الحامضية للمحلول، زاد النقص في وزن السبيكة. والتغير في الرقم الهيدروجيني للمحاليل بمرور الزمن يعزو إلى تحلل نواتج التآكل. كما أوضحت النتائج بأن معدل التآكل إنخفض بمرور الزمن في جميع المحاليل. وأظهرت نتائج الفحوصات بالمجهر الضوئي والمجهر الالكتروني بأن التآكل النقري (Pitting) والتآكل بين الحبيبات (Intergranular) قد حدث في جميع العينات التي غُمرت في المحاليل الحامضية، وكلما قل الرقم الهيدروجيني كان التآكل أكثر شدة.

## ABSTRACT

Aluminum-lithium alloys are attractive alternatives to conventional aluminum alloys for the development of light-weight fuel efficient aircraft. The corrosion resistance of an advanced 8090 aluminum-lithium (Al-Li) alloy at the peak-aged is currently being evaluated through weight loss and corrosion rate measurements in environments spanning the entire range of acidic pHs, namely, pH1, pH2, pH4, and pH5. Tests (performed according to ASTM G-31) reveal that during the three weeks immersion period, weight losses of the alloy occurs in all acidic solutions. The results indicate that the more hostile the solution, the higher the weight loss. The changes of the PH of the solutions with time are attributed to the hydrolysis of the corrosion products. The results also show that the corrosion rates are decreased with time in all solutions. The optical and scanning electron microscope results reveal that enhancement of intergranular attack and pitting have occurred for all specimens immersed in all of the acidic solutions, however, the lower the pH the more severe the attack.

**KEYWORDS:** Aerospace materials; 8090-T851 aluminum wrought alloy; Corrosion.

## INTRODUCTION

Al-Li alloys are attractive to aerospace industry due to their good properties and weight saving. Aerospace engineers will be able to save 10-15% or more in weight of an airframe by using these alloys [1, 2]. But, the peak-aged condition, the ductility and fracture toughness of these alloys are below that of conventional aircraft alloys [3]. Service experience with the commercial application of alloy 2020 showed no problem associated with either general corrosion or stress corrosion cracking [4]. It was reported [5, 6] that the presence of lithium (highly reactive element) may enhance the corrosion of Al-Li alloys in moist or saline environments. The influence of these environments with different acidity on the corrosion behavior of Al-Li alloys has been an important issue due to the various applications of these alloys, and thus their uses are depended on maintaining good corrosion resistance.

Niskanen and coworkers [7] showed that the poor corrosion behavior of Al-(1-3)%Li alloys with additions of Mn, Mg, Zr, or Cu was due to the formation of equilibrium  $\delta$  (AlLi)-phase. Stokes and co-workers [8] evaluated the corrosion characteristics of a quaternary Al-Li-Cu-Mg alloy with zirconium additions in marine environments, and they observed that the alloy at the peak-aged condition suffered from pitting, crevice corrosion, and exfoliation corrosion. Meletis and co-workers [9] studied the stress corrosion cracking (SCC) behavior of Al-Li-Cu-Zr and Al-Li-Zr alloys, and they found that the Al-Li-Zr exhibited better SCC resistance than Al-Li-Cu-Zr, while both alloys exhibited better corrosion resistance at the peak-aged condition, and the susceptibility of Al-Li-Cu-Zr was attributed to the precipitation of  $T_1$  ( $Al_2CuLi$ )-phase. Gregory and co-workers [10] conducted studies to quantify the corrosion behavior of Al-Li alloys immersed in 3.5% NaCl with respect to  $\delta$ -phase content. They found that when the volume fraction of the  $\delta$ -phase was greater than 10%, catastrophic general corrosion occurred, and that was attributed to the dissolution of the  $\delta$ -phase during long times. However, an improvement of the corrosion behavior of these alloys observed when the volume fraction of the  $\delta$ -phase was less than 10%.

The objective of this study was to evaluate the corrosion behavior of the peak-aged of the Al-Cu-Mg-Li-Zr (8090-T851) alloy by means of weight loss and corrosion rate methods, and to characterize the nature of corrosion.

## EXPERIMENTAL PROCEDURE

The Al-Li alloy (8090-T851 type) used in this investigation was in the form of an extruded plate 100 mm by 25 mm by 3 mm. Table (1) gives the chemical composition of the alloy.

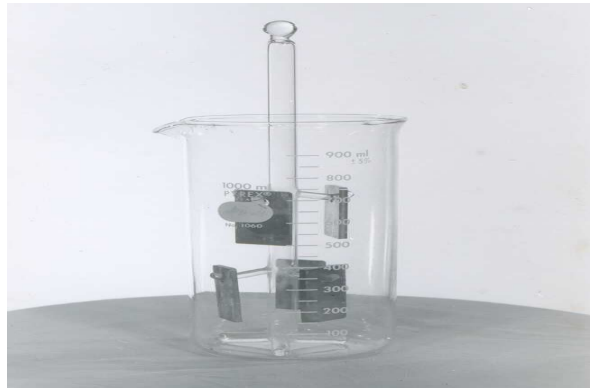
**Table 1: Chemical Composition of Al-Li Alloy.**

Element	Li	Cu	Mg	Zr	Fe	Si	Zn	Ti	Mn	Ga	Cr	Al
Wt.%	2.8	1.2	0.7	0.12	0.05	0.02	0.03	0.03	0.002	0.003	0.005	Bal.

The Corrosion specimens of the alloy were cut from the as-received (age hardened) plate and measured using Vernier Caliper to the dimensions of 42 mm by 25 mm by 3 mm. The specimens were wet ground using 240, 320, 400, and 600 grit papers, followed by polishing with 1.0 and 0.05  $\mu$ m alumina media, then rinsed in ethanol, dried in hot air, and stored in a desiccator until testing. Before testing, the specimens

were weighed to the nearest milligram using a Mettler Instrument Corporation balance. The corrosion specimens mounted on a glass rack, and each rack carried six specimens. The glass rack with coupons was immersed in a beaker containing a solution of the desired pH as shown in Figure (1).

The Corrosion tests were carried out according to the ASTM-G31 [11] standard. The desired pH solution prepared by dissolving 35 grams of NaCl in distilled water to get a stock solution of 3.5% NaCl (0.5N). The required amounts of hydrochloric acid were added to prepare solutions with starting pH1, pH2, pH4, and pH5. The beakers covered with Parafilm during the entire testing period in order to minimize contamination of the solution and possible loss due to evaporation. The adequate ratio of solution volume to specimen area was maintained at 40 ml/cm<sup>2</sup>. The corrosion specimen removed at selected times intervals, and then cleaned and weighed to the nearest 0.01 gram. The cleaning procedures were carried out according to the standard ASTM-G1, and changes in the pH of the solutions were checked at intervals of 24 hours.



**Figure 1: Glass rack carrying corrosion specimens immersed in 1 liter 3.5% NaCl solution adjusted to a desired pH.**

The Weight differences were determined from uniform corrosion rates in terms of mils per year (mpy). The average corrosion rate was obtained using equation (1):

$$\text{Corrosion rate (mpy)} = [K \times W] / [A \times T \times D] \quad (1)$$

where W is the weight loss to the nearest gram, K a constant value of  $3.45 \times 10^6$ , T the time of exposure in hours, A the surface area of the specimen in cm<sup>2</sup>, and D the alloy density (2.50 g/cm<sup>3</sup>). Both optical and SEM techniques were used to observe the surfaces and cross section areas of the corroded specimens to determine the corrosion characteristics of the alloy.

## **RESULTS AND DISCUSSION**

### **As-Received Alloy Microstructure**

The optical microscopy reveals partially recrystallized grain structure with unrecrystallized grains elongated parallel to the extrusion direction (due to cold working) of the plate. A fine dispersion of particles distributed in the grain and subgrain boundaries as shown in Figure (2). The microstructure of 8090-T851 was discussed in details

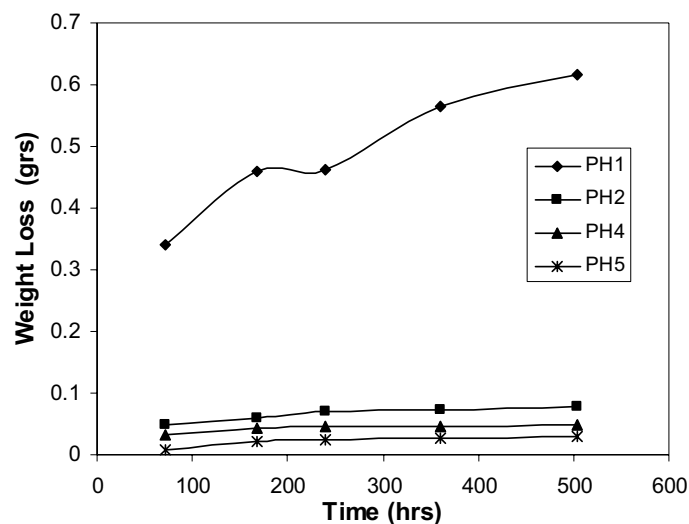
elsewhere [12]. Several microstructural studies showed that the Al-Li-Cu-Mg-Zr alloys contain various precipitating particles, such as  $Al_2CuLi$ ,  $Al_3Li$ ,  $AlLi$ ,  $Al_6CuLi_3$ ,  $Al_2MgLi$ ,  $Al_3Zr$ , and  $Al_7Cu_2Fe$  [13-17].



**Figure 2: Optical micrograph showing the fine dispersion of particles along the grains and subgrain boundaries of the 8090-T851 alloy in the longitudinal direction (275x).**

### Weight Loss

Figure (3) shows clearly that the weight loss of the specimen in solution of pH1 is several times greater than the weight loss of the specimens in the solutions of pH2, pH4, and pH5.



**Figure 3: Variation of weight loss with time of 8090-T851 alloy in 3.5% NaCl solution adjusted to pHs 1, 2, 4, and 5.**

It is evident that the weight loss of the specimen in solution of pH1 begins at high rate and progressively increases as time of the testing increases, while the other specimens show a

lower rate of weight loss. The weight loss of the alloy specimens results from uniform attack and localized attack on the active lithium bearing phases present in the alloy [18,19], the grain boundary precipitates [20], and the high angle and low angle boundaries [20].

#### Solution Chemistry

Aluminum is a reactive metal and forms an oxide/hydroxide surface film with water at room temperature. This film protects the aluminum metal from further reaction, and passivating the metal. However, this protective film is affected by the acidity or alkalinity of the solution and the presence of other ions such as chloride in the solution. Figure (4) shows the variation of the pH of the corrosion solutions with time.

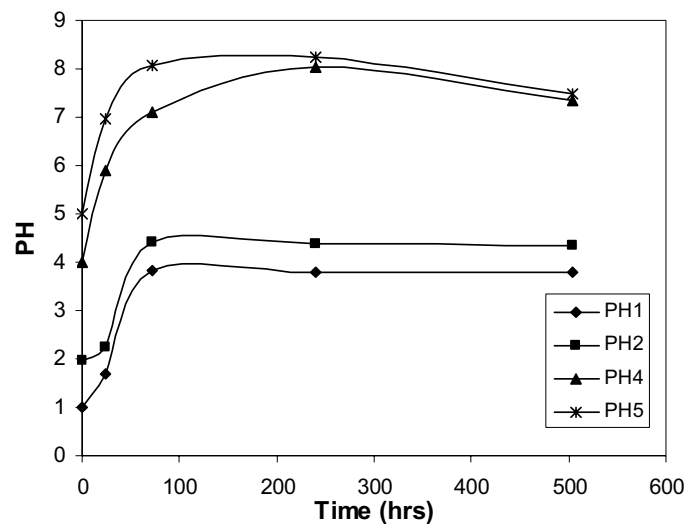


Figure 4: Comparison of the variation of the solution pH with time.

The pH of solutions of pH1 and pH2 increases to approximately the starting level of pH4 within 100 hours after the corrosion specimens are immersed, indicating that active corrosion of aluminum alloy took place, which can be represented by aluminum dissolution and hydrogen evolution reactions:



Similar behavior happens with solutions of the pH4 and pH5 that change in the same interval toward a common value of approximately the starting level of pH7.5. The corrosion was slow due to the formation of oxide/hydroxide film on the metal surface, and the cathodic reaction became as oxygen reduction rather than hydrogen evolution:



The last two reactions appeared to be dominant at exposure time higher than 100 hours.

Edeleanu and Evans [21] showed similar results for the acidic solutions, and explained their results of the pH changes that the acid solutions of pH1, pH2, pH4, and pH5 behave as the anodic reaction (2); and as the cathodic reaction in two ways either removal of H<sup>+</sup> ions by discharge as in reaction (3); or the reduction of dissolved oxygen to OH<sup>-</sup> as in reaction (4); when the product of the concentration [Al<sup>3+</sup>][OH<sup>-</sup>]<sup>3</sup> reaches the solubility product of the aluminum hydroxide, the anodic reaction becomes as in reaction (5); thus the consumption of hydroxyl ion at anodic sites is balanced by the production of the hydroxyl ion at the cathodic sites. As a result the pH of the corrosion solution should undergo no further change.

Sedriks and his coworkers [22] found for an aluminum 7075 alloy that the pH values of the solutions initially at pH1 and pH2 increased dramatically during the first hours of immersion and reached approximately pH4 level and then stayed more or less constant. They rationalized this change in pH on the basis of the arguments of Edeleanu and Evans [21]. Langan and his coworkers [23] studied 7XXX series powder metallurgy of aluminum alloys in solutions of pH1, and they noticed that the pH of the solutions increased to approximately pH4 after which no further change of pH took place. They suggested that the dissolution of aluminum, aluminum-hydroxide and related species had occurred, which was in agreement with Edeleanu and Evans studies [21].

### Corrosion Rate

In all acidic solutions, the corrosion rate decrease with time as shown in Figure (5), indicating that the more hostile the solution, the higher the corrosion rate.

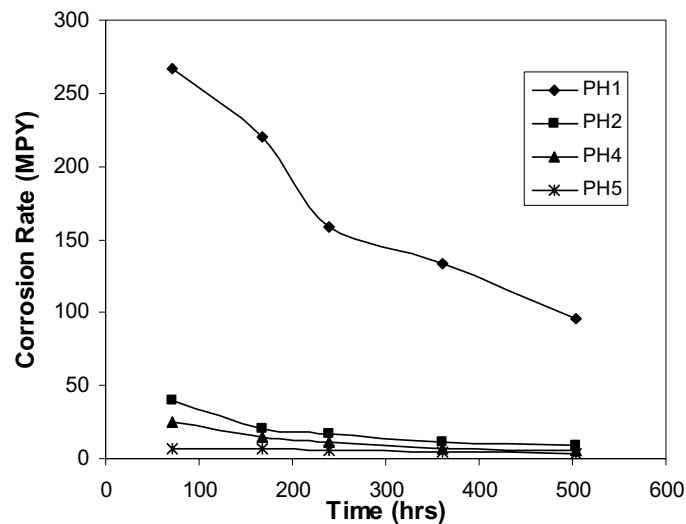


Figure 5: Variation of corrosion rate with time of all specimens in all solutions.

The corrosion rate of pH1, pH2, and pH4 start at higher rates during the first days of immersion, and then progressively decrease through out the testing period, which are in good agreement with the initial high rates of weight loss that have occurred in this type of environment. However, the corrosion rate of pH5 starts at a low rate during the first days

of testing and then stays almost constant latter. The higher corrosion rate in the acidic solutions is resulted in uniform corrosion, pitting, and intergranular attack throughout the exposure period, while the decrease in the corrosion rate is attributed to the formation of a protective film, and shift in solution pH level [15]. Pitting corrosion may be attributed to the Cl<sup>-</sup> in the solution, especially at high pH values of 4 and 5, where the passive film may form on the metal surface.

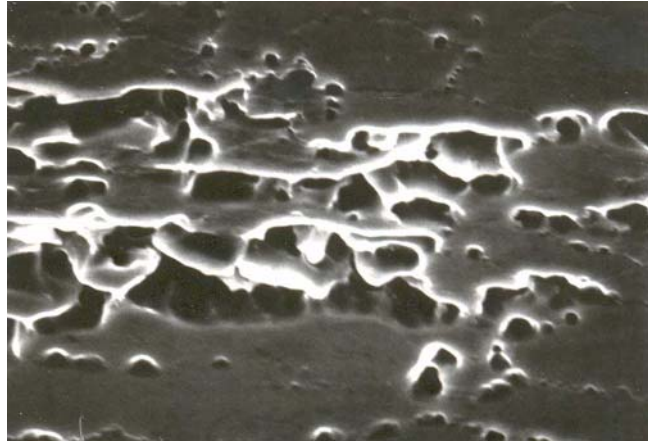
### 3.5 Corroded Specimens Microstructures

Intensive examination of the surface and cross sections of the corrosion specimens at both low and high magnification show the types of corrosion that occur to the alloy 8090-T851 in this investigation. Uniform general corrosion, the most destructive form is observed clearly after immersion in solution of pH1. This form of corrosion is characterized by an evenly distributed attack over the alloy surface. Pitting after immersion in all solutions, and the degree of attack is higher for specimens in solutions of pH1 and pH2 as shown in Figures (6 and 7). An intergranular attack is characterized by attack along the grain and subgrain boundaries of the alloy.



**Figure 6: Optical micrograph of the cross section of alloy 8090 after immersion in solution of pH 5 for 360 hours showing a large pit with intergranular attack (275x).**

This mechanism causes deep local penetration and rapid destruction of the mechanical properties of the alloy, and occurs for all specimens. The degree of attack is higher for more acidic than for the mild ones, pH1 is suffered the most, then pH2, pH4, and pH5 respectively. This is in agreement with the weight loss and corrosion rate that occur for the specimens in all solutions. The pits that form are caused by an accelerated dissolution of the passive film and the metal substrate.



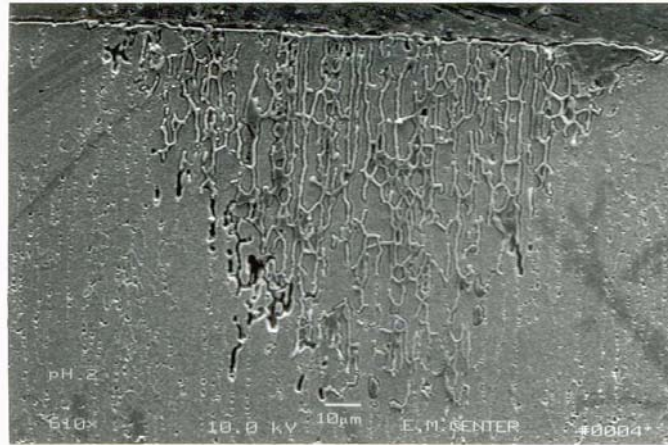
**Figure 7: Scanning electron micrograph of the surface of alloy 8090 exposed to solution with pH1 for 120 hours showing pits attacking the particles along the grain and subgrain boundaries (2000x).**

The mode of corrosion is intergranular attack. The degree of the attack increased both with increasing aggressiveness of the solution and the exposure time to the solution. The intergranular attack that occurs in the specimens immersed in the solutions of pH1 is the most severe than pH2 and pH5 as shown in Figures (8,9 and 10) respectively.

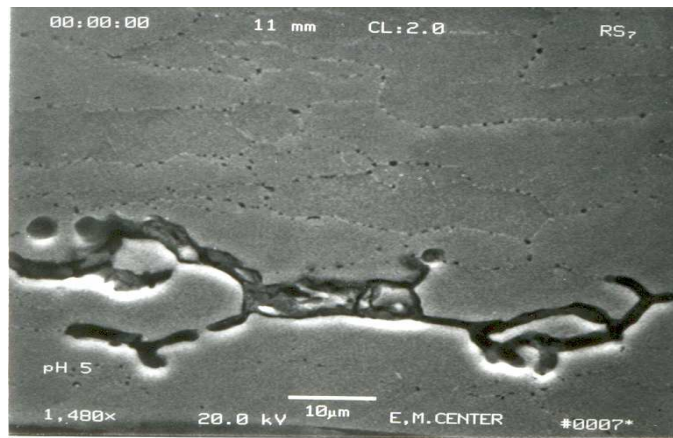


**Figure 8: Optical micrograph of the surface of alloy 8090 after immersion in solution of pH1 (275x).**





**Figure 9: Scanning electron micrograph of the cross section of alloy 8090 exposed to solution with pH2 for 360 hours showing the degree of intergranular attack (610x).**



**Figure 10: Scanning electron micrograph of the surface of alloy 8090 exposed to solution with pH5 for 360 hours showing the degree and path of intergranular attack (1480x).**

## CONCLUSIONS

- This study reveals that corrosion attack occurred for all specimens in all acidic environments.
- Weight loss occurs for all specimens. However, the weight loss in the more acidic solution is several times greater than the weight loss in the less acidic solutions. The incremental weight loss decreases monotonically with time.
- The pH of the original solutions changes during the test period. Solutions of pH1 and pH2 become constant at approximately pH4 after 100 hours. However, solutions of pH4 and pH5 become constant at approximately pH7.5.
- Corrosion rate (as expressed in mils per year (mpy)) progressively decreases with time in all acidic solutions.
- In all acidic solutions, pitting and intergranular corrosion are observed, however the intensity of the intergranular corrosion is higher. Also, uniform general

corrosion has occurred for all specimens, but pH1 has suffered the most. Pitting corrosion is may be attributed to the presence of Cl<sup>-</sup> in the solution, especially at high pH values.

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