

THE EFFECTS OF CORROSION ON THE MECHANICAL PROPERTIES OF ALUMINIUM ALLOY 7075-T6

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Obiectivul acestei lucrări îl reprezintă analiza efectului coroziunii asupra rezistenței statice și la oboseală pentru aliajul 7075-T6. Probele testate au fost tăiate dintr-o folie plată de aluminiu și acoperite cu o mască pentru a restricționa aria de coroziune. Coroziunea a fost accelerată cu ajutorul unei celule galvanice. După coroziune probele au fost testate la efort și oboseală. Efectul coroziunii asupra rezistenței statice a rezultat într-o scădere inițială puternică a rezistenței, urmată de o reducere liniară proporțională cu pierderea de masă prin coroziune. Reducerea rezistenței la oboseală prin coroziune a tins să respecte o reducere invers proporțională cu pierderea de masă prin coroziune. Chiar un nivel de coroziune scăzut reduce dramatic rezistența la oboseală a aliajului de aluminiu.

The objective of this research was to analyze the effects of corrosion on the static strength and fatigue life of 7075-T6 aluminum alloy. Test specimens were cut from flat sheets of aluminum and covered with masking material to restrict corrosion to a confined area. The corrosion process was accelerated by use of a galvanic corrosion cell. After corrosion, specimens were tested in tension and fatigue. The effect of corrosion on the tensile strength resulted in a large initial drop in strength, then a linear reduction in strength as mass loss increased. The tensile strength was observed to reduce significantly at low mass loss levels. The reduction of fatigue life due to corrosion tended to follow an inverse exponential reduction as mass loss increased. Even small amounts of corrosion reduced the fatigue life of the aluminum alloy drastically.

Keywords: aluminum alloy, corrosion, tensile strength, fatigue life

1. Introduction

High strength aluminum alloys such as 7075-T6, are widely used in aircraft structures due to their high strength-to-weight ratio, machinability and low cost. However, due to their compositions, these alloys are susceptible to corrosion. Corrosion is a major concern involving the structural integrity of aircraft structures. Corrosion has been shown to reduce the life expectancy of these structures considerably. Aircraft during normal operation are subjected to natural corrosive environments due to temperature.

Among the issues facing aging aircraft, corrosion in combination with fatigue is extremely undesirable. Corrosion can reduce the life expectancy of aircraft

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structures considerably. Corrosion on aircraft can be attributed to natural environmental factors such as humidity, rain, temperature, and salt water. Because of this impact on the life of aging aircraft, there is a need to understand, quantify, and monitor the corrosion process, particularly as it relates to structural fatigue life. There is need to quantify the effects of corrosion on the mechanical properties of Al 7075-T6. The quantification of mass loss, due to pitting corrosion, as a function of static strength and fatigue life could be a useful measure in the maintenance of aging aircraft.

Aluminum is highly resistant to weathering, even in many industrial atmospheres, which often corrode other metals. It is also resistant to many acids.” Although aluminum has a huge advantage when compared to other metals, it is not always completely impervious to corrosion. Its protective oxide layer can become unstable when exposed to extreme pH levels. When the environment is highly acidic or basic, breakdown of the protective layer can occur, and its automatic renewal may not be fast enough to prevent corrosion.

Aluminum’s protective oxide film is generally stable in the pH range of 4.5 to 8.5, but the nature of the compounds present is crucial, certain soils tend to be corrosive to aluminum, particularly non-draining clay-organic mucks. As a general rule, contact with clay soils should be minimized unless special corrosion treatment measures are instituted.

Galvanic corrosion is the most common cause of aluminum corrosion due to its inherent resistance to more natural forms of corrosion and a lack of preventative measures taken. Aluminum is typically a reactive metal in the galvanic series. This means that in many cases, when it is in contact with other metals, aluminum will act as the anode and may begin to corrode. Although this process may take many years to yield signs of degradation, it is very easy to preclude.

2. Experimental

The objective of this experiment was to quantify the effects of corrosion, based on mass loss, on the static strength and fatigue life of 7075-T6 aluminum alloy. To obtain this objective, test specimens were cut from flat sheets of aluminum and covered with masking material to restrict corrosion to a confined area. The corrosion process was accelerated by use of a galvanic corrosion cell. After corrosion, specimens were tested in tension and fatigue. Specimens were corroded to mass loss levels of 0, 5, 10, 15, 20, 25, and 30%. Tensile and fatigue tests were performed on the corroded and uncorroded samples and the results were interpreted.

This experiment required only a small rectangular area on one side of the specimens to be corroded. Therefore, it was necessary for the remainder of the specimen to be protected from the corrosive environment by means of masking. 3-

M Corrosion Resistant Tape was used as the masking material. An example of a masked specimen can be seen in figure 1. The specimens were submerged and allowed to corrode in the galvanic corrosion cell. Using more specimens to be corroded at a time allowed for two control samples to be removed early from each cell to ensure mass loss rates experienced matched those predicted. During the corrosion process, the current supplied to each specimen was recorded daily to determine the mass loss rate.

The masked specimens were submerged vertically in the salt water and connected to the positive lead of the power supply. The graphite rods were submerged and connected to the negative lead. The power supply was used to apply an induced voltage across the corrosion cell, which varied from 750 to 850 mV. The experimental system is shown in figure 2.



Fig.1 - Masked Specimen Showing Exposed Area to Be Corroded



Fig.2 - Galvanic Corrosion Cell -Front View

The samples were tested to failure for each level of mass loss. The uncorroded samples were tested to determine the ultimate tensile strength of the material. The tensile strength of the undamaged specimens was used in comparison with that of the corroded samples to determine the effects of corrosion on the reduction in tensile strength of the material.

After the samples were corroded it was noticed that the bottom edge of the specimens experienced the most severe corrosion. During testing, failure occurred most often at the bottom edge due to the fact that it had the thinnest cross sectional area. This prompted an investigation of fatigue life vs. thickness. The thickness was determined by two methods: direct measurement and calculations based on mass loss. In order to determine the thickness by direct measurement, the corrosion product on the specimen was scraped away from a small spot on the fracture surface, and the resulting thickness was measured using vernier calipers. Thickness was also calculated by assuming uniform corrosion on the exposed surface and therefore a uniform reduction in thickness. The estimated thickness was calculated using equation 1:

$$t_{\text{calc}} = (M_0 - AM) / (w * L * \rho) \quad (1)$$

where: t_{calc} = effective thickness, M_0 = original mass

AM = change in mass ; w = width of effective area.

L = length of exposed area ; ρ = density of 7075 T6 aluminum (2.80 g/cm^3).

3. Results

The mass loss for each specimen was compared to the average current measured during corrosion multiplied by the time required for corrosion. The reason for multiplying the current by the time of corrosion is due to the difference in current for each specimen. Since the current varied for each specimen, the time required to obtain the same mass loss also varied. Multiplying the current by the time gave a consistent basis of comparison. The results are shown in figure 3 and the tabulated data is included in Table 1. As seen from figure 3 mass loss increases linearly as the product of current and time increases. This result was used to predict the time required to corrode test specimens to target mass loss levels.

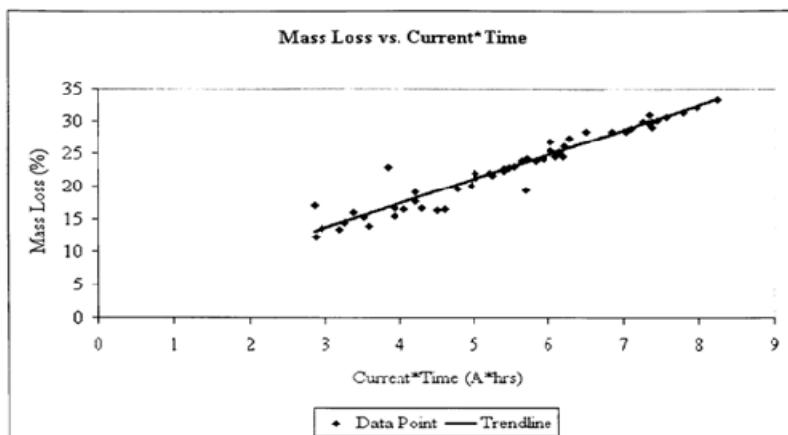


Fig.3 Mass Loss versus (Current * Time)

The tensile test results of samples tested at different mass loss levels due to corrosion are shown in figure 4. The ultimate strength curves were calculated using the original non-corroded cross sectional area and the calculated effective cross sectional area. A comparison of the two curves shows that the values for the ultimate strength obtained from the effective area were higher than the strengths obtained from the original area calculations which are due to the fact that the effective area is smaller than the original area. As seen in this figure, the strength of the aluminum tends to reduce linearly with increasing mass loss.

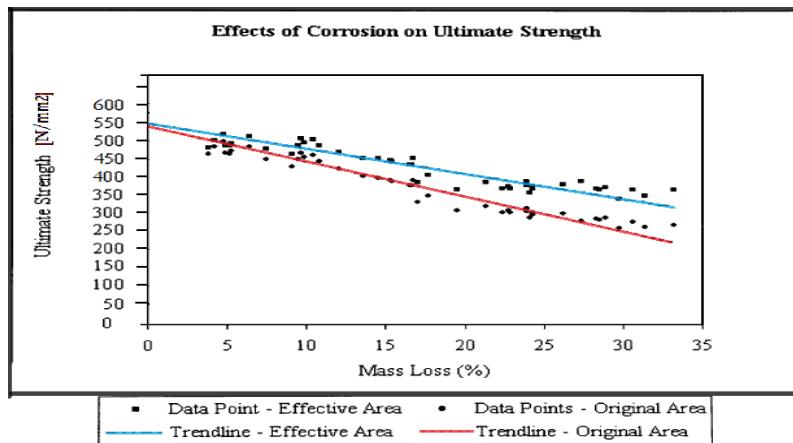


Fig.4 - Tensile Test Data

The ultimate strength was then calculated using the following equations:

$$\sigma_{ut_o} = F_{max} / A_o \quad (2)$$

$$\sigma_{ut_a} = F_{max} / A_e \quad (3)$$

where: σ_{ut_o} = Ultimate strength assuming original cross sectional area

σ_{ut_a} = Ultimate strength assuming effective cross sectional area

F_{max} = Maximum force recorded during testing

A_o = Original cross sectional area; A_e = Effective cross sectional area.

The results of the fatigue test conducted on samples of different mass loss due to corrosion are shown in figures 5 and 6. To further investigate the reduction of fatigue life, the results of the corroded samples were plotted without the presence of the results from the undamaged specimens; this is shown in figure 5. As illustrated by Figure 6, the effect of corrosion tends to follow an inverse exponential trend.

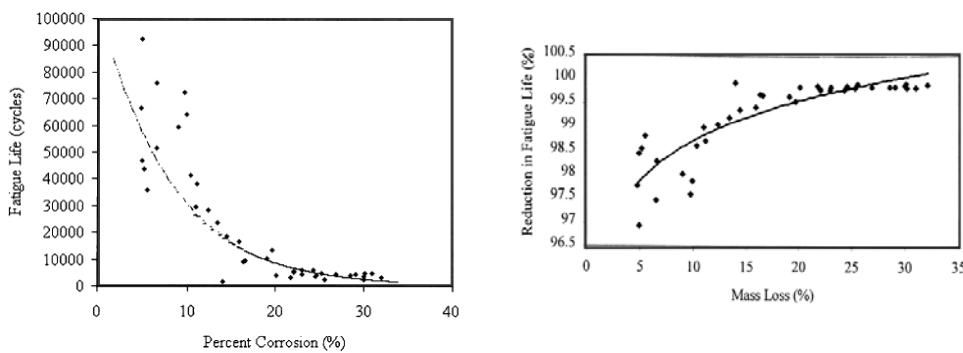


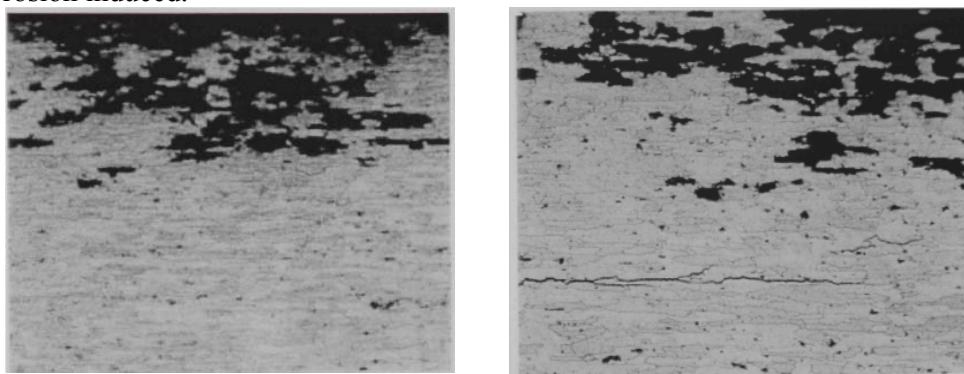
Fig.5 - Fatigue Test Data (Corroded Specimens Only)

Fig.6 - Percent Reduction in Fatigue Life Due to Corrosion

More specifically, the difference in average cycles to failure from 5 to 15% mass loss is approximately 46000; whereas the difference in average cycles from 20 to 30% mass loss is approximately 3000.

To further illustrate the effects of corrosion on the reduction in fatigue life, a plot was made of the percent reduction in fatigue based on a safe fatigue life of 3 million cycles. The result of this comparison is presented in Figure 6. As indicated by Fig. 6, due to the mass loss increases the percent reduction in fatigue life increases. Small amounts of corrosion reduced the fatigue life of the aluminum drastically. For example, the average life of samples tested with 5% mass loss was 58904 cycles which corresponds to approximately a 98% reduction in fatigue life compared to the undamaged samples which lasted 3 million cycles. This is a significant reduction in fatigue life even though the undamaged specimens were stopped soon after 3 million cycles and not tested to failure.

The resulting images of the samples cut from corroded areas of untested specimens are shown in Figures 7 (a) and (b). These figures show that the corrosion penetrates into the thickness of the metal deeper than can be seen at the surface. The resulting subsurface corrosion creates areas of high stress concentration and results in the reduction of strength and fatigue life. The section cut from the Y (vertical) axis shows an internal crack believed to be induced by corrosion in combination with residual stresses present in the test material. A detailed examination of the crack shows that it is running along the grain boundaries and not across them. This observation indicates that this crack is corrosion induced.



(a) Horizontal cut (100X)

(a) Vertical cut (200X)

Fig.7 - Microstructure of Corrosion Samples

4. Conclusions

The following conclusions were found:

1. Corrosion reduced the ultimate strength of the aluminum alloy considerably, even at low mass loss.

2. After corrosion is initiated there appears to be a linear decrease in strength with increasing mass loss.
3. The fatigue life appears to follow an inverse exponential reduction in life as mass loss increases.
4. Similarly, the fatigue life decreases in an inverse exponential fashion with decreasing thickness.
5. Small amounts of corrosion reduce the fatigue life of the aluminum alloy significantly.
6. Specimens tended to fail more often at the bottom edge of the exposed area in fatigue and tension due to more severe corrosion, which resulted in a thinner cross sectional area, experienced at that location. This was more evident at higher mass losses.
7. Localized areas of corrosion existed below the visible corrosion surface.

R E F E R E N C E S

1. *Alina Daniela Neculescu - Teză de doctorat „ Utilizarea modelării matematice la analiza factorilor care influențează structura și proprietățile aliajelor de aluminiu ”.*