Determination of Stress-Corrosion Cracking in Aluminum-Lithium Alloy ML377

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Abstract

The use of aluminum-lithium alloys for aerospace applications is currently being studied at NASA Langley Research Center's Metallic Materials Branch. The alloys in question will operate under stress in a corrosive environment. These conditions are ideal for the phenomena of stress-corrosion cracking (SCC) to occur. The test procedure for SCC calls for alternate immersion and breaking load tests. These tests were optimized for the lab equipment and materials available in the Light Alloy lab. Al-Li alloy ML377 specimens were then subjected to alternate immersion and breaking load tests to determine residual strength and resistance to SCC. Corrosion morphology and microstructure were examined under magnification. Data shows that ML377 is highly resistant to stress-corrosion cracking.

Background

The High Speed Research program, or HSR, is a joint program between NASA and industry, concerned with developing the next generation of supersonic civil aircraft. Many factors must be studied, including structures, materials, design, commercial feasibility, noise, and pollution. The development of these technologies is necessary to the success of a high speed civil transport. The purposes of this study are to collect corrosion data on candidate alloys for the HSR program and to evaluate the breaking load test method for stress-corrosion cracking. The material tested in this study is aluminum-lithium alloy ML377 in the T8 (near peak aged) condition. This is the most corrosion resistant temper for Al-Li alloys, and is the first of several alloys to be tested.

The phenomena of stress-corrosion cracking (SCC) can lead to catastrophic engineering failures. Many parts in an aircraft frame are subjected to conditions that could lead to SCC. In order for SCC to occur high levels of stress must act in conjunction with a corrosive environment. The breaking load method can be used to determine a threshold stress level for the initiation of SCC. Material below this stress level would be safe from the possibility of SCC.

The breaking load test method determines the residual strength of an alloy after exposure to SCC conditions. Specimens are fixed in stress by static load frames. The specimens are subject to corrosion by alternating immersion and drying cycles in a sodium chloride solution. They are then stressed to failure in tension. By using a test matrix of varying stress levels and exposure times, an alloy's resistance to SCC can be determined. The breaking load method can determine the SCC initiation threshold with fewer specimens and shorter times than traditional pass-fail tests, and can detect differences in highly resistant alloys.

Procedure

Test Procedure

The test procedure involves two major phases. Specimens are exposed to a corrosive environment for a range of stress levels and times in alternate immersion, then they are subject to tensile failure. The specimens are transverse dog bone coupons of Al-Li alloy ML377 in the T8 temper (Figure 1). The gage length has been polished to meet ASTM standards.

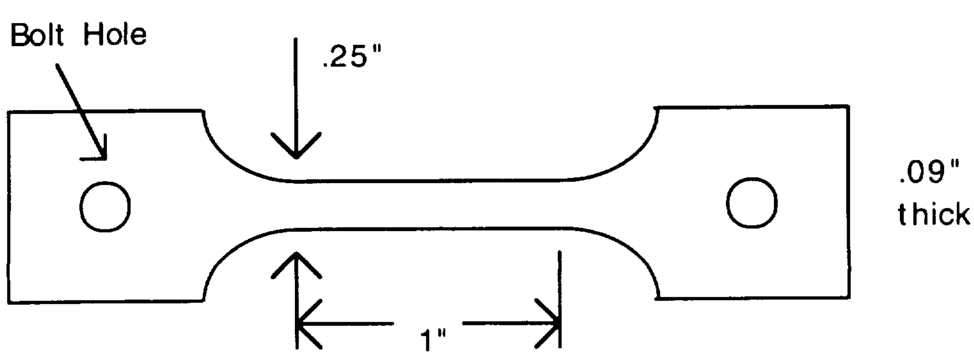


Figure 1 - ML377 Dog Bone Specimen

The static load frame (Figure 2a) is made of steel and protected with a special coating, in order to prevent any rust or galvanic cell formation. The spring has a spring constant of approximately 2200 lbs/in. When loaded, the spring applies pressure to a stainless steel threaded rod, which is connected to the specimen via bolts. A nut on the rod allows adjustment of the stress placed on the alloy. The elongation of the specimen is monitored by an extensometer attached to the specimen. The stress is calculated from the extension and modulus of the specimen. Once the specimen connectors have been protected with wax and the gage length has had all extensometer marks removed, it is placed in the immersion tank.

a) b)

Figure 2 - a)Static Load Frame b)Specimens in Alternate Immersion Tank

The alternate immersion test (Figure 2b) subjects the specimen to ten minutes of exposure to a corrosive solution and fifty minutes drying time. The solution used was 3.5% by weight sodium chloride in distilled water. The environmental conditions of the test lab are maintained at 80°F ± 2° and 40% humidity ±6%. A timer is used to raise and lower the water level in the main test tank. The timer is connected to a pump, which moves water from a reservoir tank to the main tank, and a solenoid, which drains from the main tank to the reservoir. Water levels are monitored to assure a proper solution concentration.

Once alternate immersion exposure is complete, the specimen is removed, unloaded, and examined for any anomalies. It is then subjected to the breaking load test. The specimen is pulled in tension until failure in a hydraulic load machine. The load at failure (ultimate tensile strength) and the load vs. elongation curve are recorded.

In addition, the corrosion morphology and fracture surfaces were examined visually under high magnification. Micrographs were taken of some surfaces to assist examination. Surfaces were then etched to relate corrosion morphology to microstructure.

Test Optimization

Before the testing could begin, it was necessary to study the testing procedure itself. The best ways to protect the frames from corrosion, load the frames, and maintain the test conditions were reevaluated.

Many different coating techniques were studied for their protection and longevity characteristics. The load frame must be protected from exposure to salt water when it is submerged. However, the gage length of the specimen in test must come in contact with the water. Wax, latex, heat shrinkable plastic, and a polymer paint known as Plasti-Dip were examined as coating materials. After extensive testing, a system of coating was chosen that combines wax and Plasti-Dip. The steel frame is coated in Plasti-Dip because it adheres well and has excellent waterproofing properties. The connections between the load bolt and the specimen are coated with wax because it is easily removed and conforms to the contours of the region.

In order for the tests to be as accurate as possible, the load frames must pull the specimen in tension. Any added bending moments or twisting forces can affect test results. Due to the design of the frame, it is easy to induce these forces when loading. Therefore, it was necessary to develop a rig for securing the frame at all points except the point of spring compression. The design of the rig uses gravity to help line the frame vertically. The top and bottom are secured and the spring is loaded by use of a wrench.

The test solution was monitored to maintain conditions. Water evaporated from solution and had to be replenished every two days. The entire tank needed to be emptied and refilled every three weeks to prevent build up of excessive metal ions in solution. A system for changing the solution was developed utilizing an extra tank system in the lab.

Results

Breaking Load Data

The data for this study was collected as the residual ultimate tensile strength of the specimen. The experimental parameters were the time of exposure and the stress level during exposure, given as a percent of the yield strength of the material. Figure 4 shows the number of specimens tested for each combination of exposure and stress.

Exposure	0% stress	50% stress	65% stress	80% stress
0 days	2	0	0	0
10 days	3	0	3	3
15 days	3	3	3	3
30 days	3	3	3	3

Figure 4 - Test Matrix for ML377 SCC specimens

Residual strength is measured as the load at fracture, or the breaking load, divided by the original cross-sectional area of the specimen. As a specimen corrodes, its cross-sectional area is reduced. By using the original area as a standard, the residual strength can be used to gauge the amount of corrosion which has occurred.

Each data point is given as an average of the residual strength of all the specimens subjected to those particular conditions, in most cases three specimens (see Figure 4). Study of the data obtained (Figures 5,6) reveals that ML377 is resistant to stress-corrosion cracking. No specimens failed while in test. Loss of strength appears to be due to general corrosion, aided by stress.

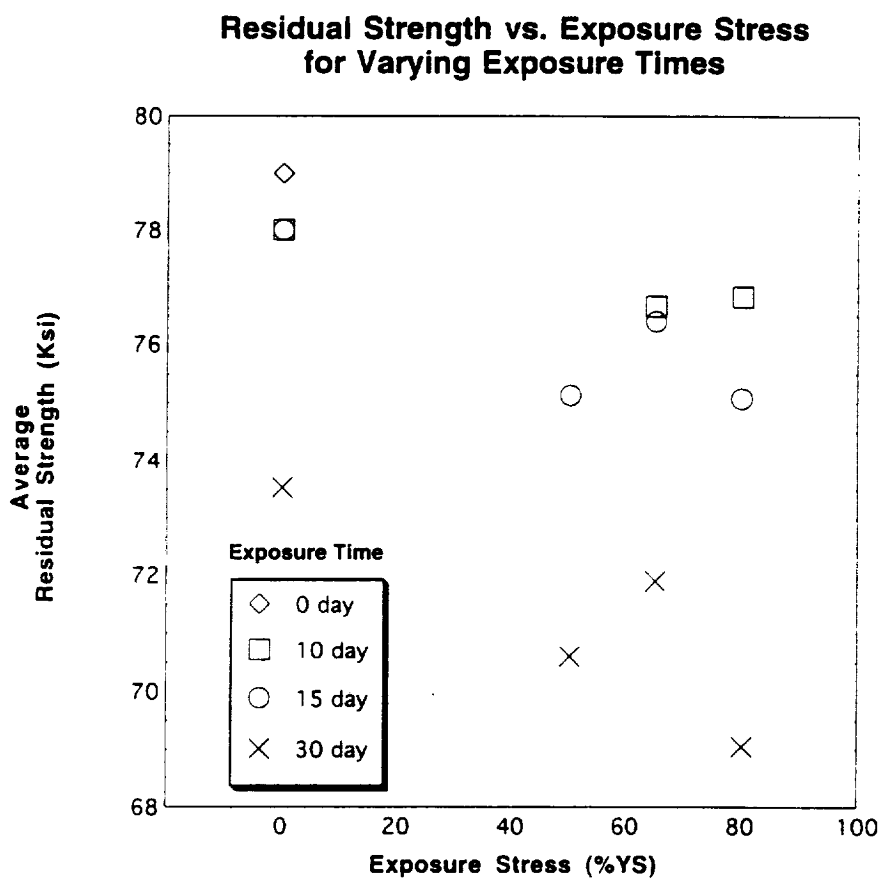


Figure 5 - Residual Strength vs. Exposure Stress

The plot of residual strength versus exposure stress (Figure 5) shows that increasing the exposure stress results in a loss of strength. There is a downward trend in residual strength with increasing exposure stress for each exposure time. The effect of stress is greater for the longer exposure times.

Figure 6 shows the same data plotted as residual strength versus exposure time for varying stress levels. For each exposure stress, residual strength decreases with exposure time.

For example, each point at 15 days is less than or equal to its partner stress level at 10 days.

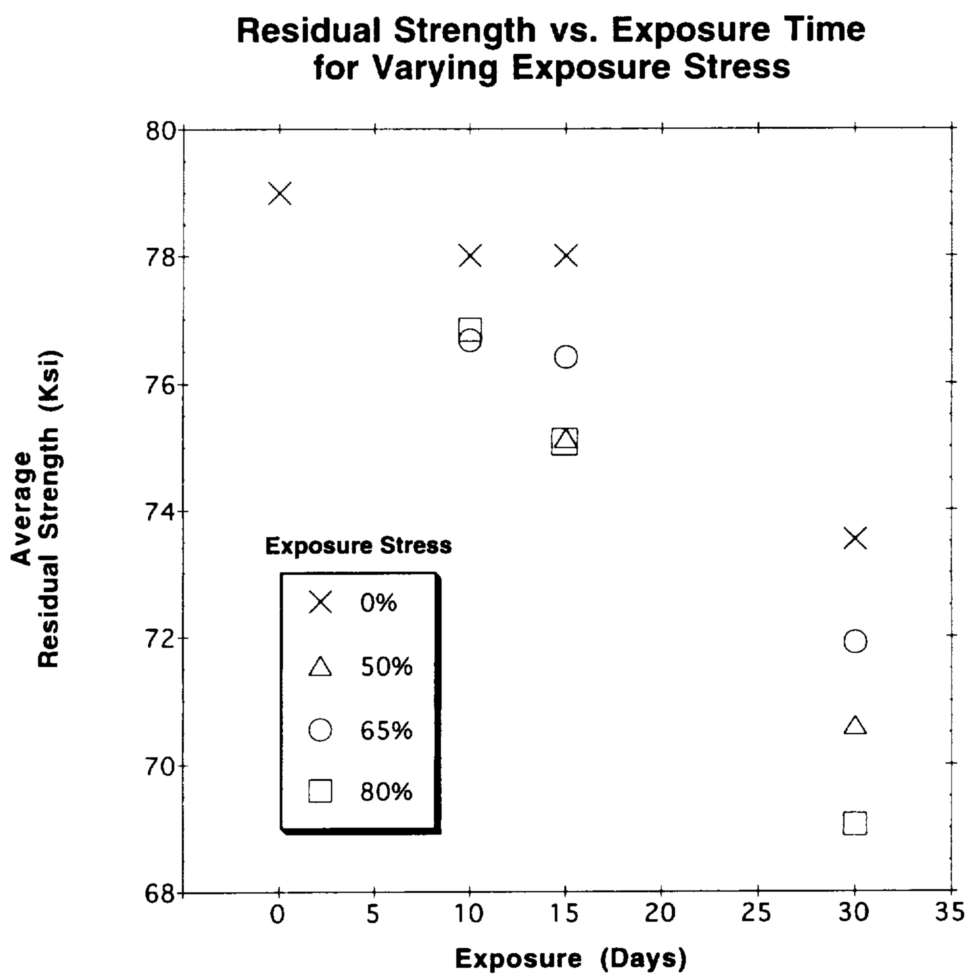


Figure 6 - Residual Strength vs. Exposure Time

For both stressed and unstressed specimens, an additional reduction in residual strength occurs after 30 days exposure. The data indicates a combined effect between stress level and exposure time. The reduction in strength of the unstressed specimen is due to pitting corrosion. The longer the exposure, the more pitting can occur, and thus a greater reduction in area results in a greater loss of strength.

After 30 days, an unstressed specimen has lost 6.7% of its original strength, while an 80% stress specimen has lost 12.7%. The reduction in strength of the highest stressed specimens is approximately double that of the unstressed specimens. This may be due to either stress corrosion cracking or stress assisted pitting.

Corrosion Morphology and Microstructure

Figure 7 shows the grain structure of the alloy, viewed in the T-S plane. Since these are transverse specimens, the rolling direction of the grains goes into the page. The grains are elongated in the rolling direction and flattened to the left and right, as expected for rolled sheet. All micrographs shown are prepared in the T-S orientation.

Figure 8 shows polished sections through corrosion pits. No stress corrosion cracks were present in any of the specimens viewed. Pitting was the only corrosion observed on the specimens. The crack propagating from the base of the pit in Figure 8a was caused by tensile fracture rather than stress corrosion because no stress was present on this specimen. Many different corrosion pits were examined from specimens exposed at the various test conditions. The pit propagation in both stressed and unstressed specimens, in general, follows the transverse direction. However, in the stressed specimens, corrosion propagation seems to be influenced by stress, causing a sharper undercutting of the surface metal, as illustrated in Figure 8b by the narrow pit opening. More material has been dissolved at the surface in the unstressed specimen (Figure 8a). The corrosion mechanism does not seem to prefer a particular grain type and proceeds through grain boundaries, illustrated in the polished and etched cross section shown in Figure 9.

For the exposure stresses and durations conducted, ML377 is resistant to stress-corrosion cracking. Any loss of strength can be contributed to a reduction in area due to pitting corrosion.

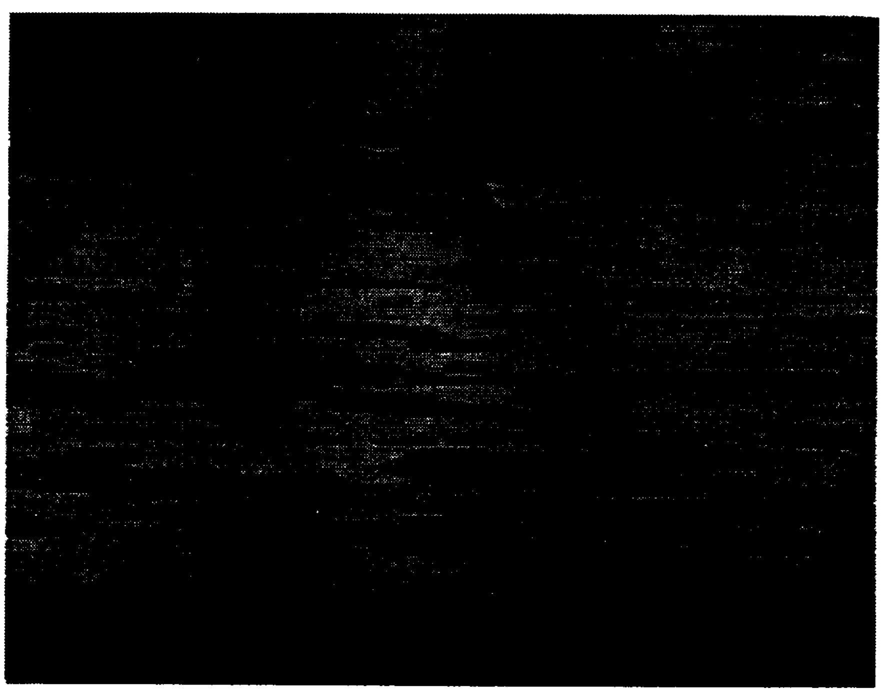
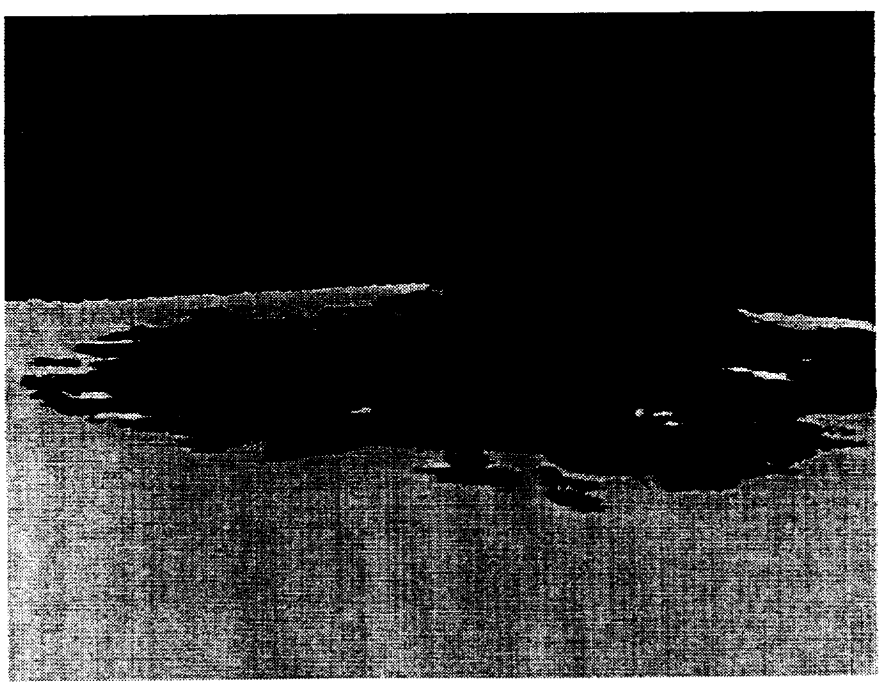


Figure 7 - Grain Structure of ML377-T8 (100X)

a)



b)

Figure 8 - a) 30day, 0%stress specimen pit b) 30day, 65% stress specimen pit (100X)

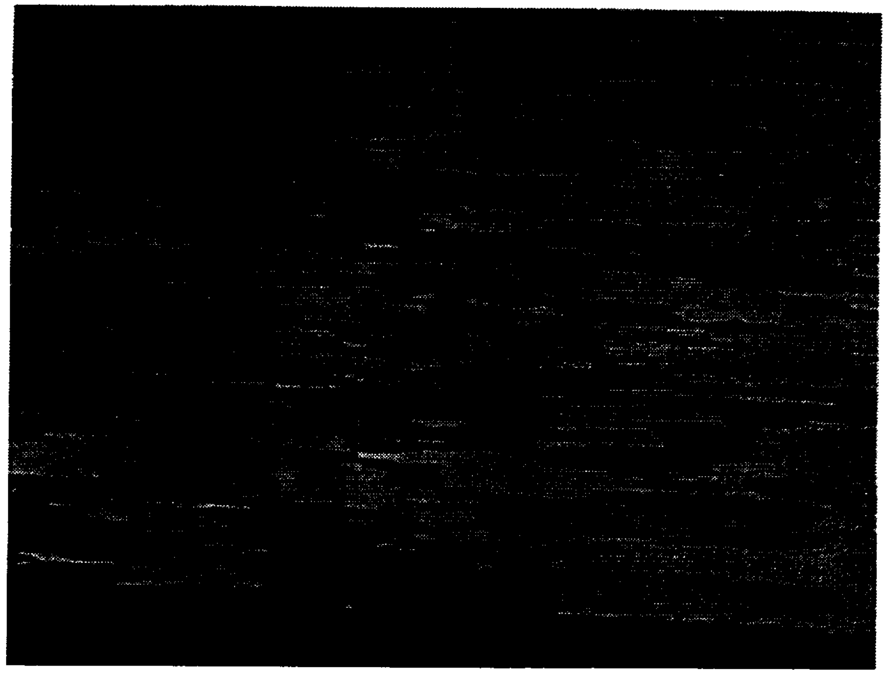


Figure 9 - Corrosion Pit and Microstructure of 30 day, 65% stress specimen (100X)

Conclusion

Aluminum light alloy ML377 in the T8 temper is resistant to stress-corrosion cracking for the parameters used in this study. A combined effect of exposure stress and exposure time is evident, however corrosion was due to stress assisted pitting rather than stress corrosion cracking. There is a difference in the corrosion morphology between stressed and unstressed specimens.

The breaking load method is showing promise as an effective method for the study of initiation of stress-corrosion cracking in resistant alloys. However, much more testing is needed before this method proves itself.