

Effect of Dynamic Humidity on Environmental Cracking of an Aerospace Aluminum Alloy

L. Agnew, B. Clark, V. Avance, F. Friedersdorf
Luna Innovations Inc.
301 1st St. SW, Suite 200
Roanoke, VA, 24011
USA

ABSTRACT

This work explores the effect of humidity and galvanic coupling on the environmental assisted crack initiation and growth rate of high-strength aluminum alloys under static load. Varied relative humidity and temperature cycles, based on relevant aircraft service environments, are used to identify factors leading to peak crack growth rate for a sodium chloride salt chemistry. The influence of dynamic environmental conditions versus constant environmental conditions are being evaluated. Aerospace materials are galvanically coupled to the aluminum substrate to quantify the effect on initiation time and growth rate. Spring-actuated double cantilever beam test systems with continuous sensor monitoring are employed in atmospheric environments with smooth-notch samples to produce estimates of time to crack nucleation, crack length, crack growth rate, and crack tip stress intensity. Simultaneous zero resistance ammeter measurement of the corrosion currents between galvanically coupled aerospace materials and the aluminum samples improves understanding of the relationships between atmospheric environment and the electrochemical processes leading to crack initiation and growth. Results demonstrate clear differences between wetting and drying processes, with peaks in galvanic corrosion current observed during drying and smaller peaks observed during wetting. Peaks in crack growth rate are observed at moderate relative humidity during drying processes.

Key words: Environmental assisted cracking, atmospheric corrosion, crevice corrosion, galvanic corrosion, stress corrosion cracking.

INTRODUCTION

High-strength aerospace aluminum alloys, such as AA7075-T651, are susceptible to environmental assisted cracking (EAC) under the right combinations of stress, environment, and microstructure. EAC presents a serious risk to structures and equipment operated in corrosive conditions. Studies of EAC in aluminum alloys have highlighted the importance of both anodic dissolution and hydrogen embrittlement to EAC initiation and propagation.^{1–4} The EAC response of alloys under variable

atmospheric conditions is of particular importance for assessing material performance for aerospace applications.

Characterization techniques for EAC of alloys often employ immersion testing with constant concentration, volume, and temperature conditions or testing under controlled thin electrolyte layers with static environmental conditions.⁵⁻⁷ There is a need for evaluation and testing of EAC performance with variable, but controlled, atmospheric environmental conditions, with in situ crack growth measurements, and electrochemical monitoring to better capture the effects of processes relevant to in-service degradation of high-strength aluminum alloy structures. Environmental cycles affect the composition and distribution of electrolyte, which can significantly impact electrochemical reactions, current distribution, and corrosion rates.⁸⁻¹¹ Additionally, crevice and cracking conditions can result in pH and concentration gradients resulting in aggressive conditions that promote EAC.^{12,13}

Many aluminum structures use more noble materials, particularly as fasteners, that are galvanically coupled and result in anodic polarization of the aluminum structure. It has been shown that anodic polarization of high-strength aluminum alloys results in accelerated EAC failure and decreased strength and ductility.^{14,15} Quantitative measurements of galvanic coupling effect and crack growth under dynamic atmospheres are needed. These measurements in laboratory tests and eventually outdoor environments would be beneficial to understand the effect of specific galvanic couples and environments on corrosion kinetics and EAC processes to better predict structural integrity and inform design and maintenance practices.

This work seeks to improve our understanding of high-strength aluminum alloy EAC to influence materials selection and design and inform development of models of aerospace structures in corrosive atmospheres. This is accomplished through corrosion rate measurements of galvanically-coupled materials with salt deposits and EAC crack growth measurements of stress specimens tested in dynamic atmospheric environmental conditions.

EXPERIMENTAL APPROACH

To investigate the affect of dynamic environmental cycles on initiation and growth of cracks, two types of experiments were performed. The galvanic corrosion rate of interdigitated electrodes under atmospheric conditions was monitored to determine the affect of relative humidity (RH) on boldly exposed surfaces, which could in turn affect the conditions in a crevice or crack. Environmental assisted cracking experiments were also performed with a galvanically coupled crevice-former over the initiation site. Crack growth rate and corrosion current between the crevice former and the sample were monitored.

Boldly Exposed Surface Measurements

Sensing devices comprising interdigitated galvanic corrosion, interdigitated solution conductance, and relative humidity sensors were used to monitor solution properties and boldly exposed galvanic corrosion rates when RH is varied (Figure 1). The galvanic sensor had a 1:1 surface area ratio of aluminum alloy 7075-T6 and stainless steel A286.

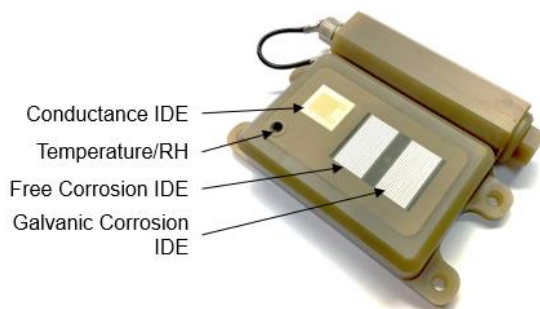


Figure 1. Environment and corrosivity monitoring device.

A hydrophilic electrolyte support membrane was used in atmospheric galvanic corrosion tests as well as EAC tests. The membrane enables even distribution of a known salt solution volume over a defined surface area. The membrane was produced by immersing 1.5 oz. plain weave E-glass fiberglass cloth in 50% w/w sodium hydroxide solution for 1 hour to induce hydrophilicity, before thoroughly rinsing in deionized (DI) water.

Experiments were performed at a constant temperature of 25 °C with a sodium chloride (NaCl) salt solution. An electrolyte support membrane was placed over the galvanic corrosion and solution conductance sensors and dosed with salt solution before placing the sensors horizontally in a controlled environment chamber. An RH profile was selected to observe corrosion rates at multiple RH values, reached by drying from above 95% RH. In one test the sensors were dosed with 605 $\mu\text{g}/\text{cm}^2$ planar density of NaCl. Each RH step was 90 minutes long before returning to 95% for 30 minutes and then rapidly drying to the next step. In the second test the sensors were dosed with 151 $\mu\text{g}/\text{cm}^2$ planar density of NaCl. Each RH step was 180 minutes long before returning to 98% for 30 minutes and then rapidly drying to the next step. Both tests began with a four-hour hold at high humidity immediately after dosing with salt solution and before the RH steps were started. Three replicate sensors were included in each experiment, and measurements were recorded on a 1-minute interval.

Environmental Assisted Crack Measurements

A static load EAC system was designed to produce rising stress intensity crack growth in a double-cantilever beam (DCB) sample that can be exposed to cyclic atmospheric environments (Figure 2). The DCB specimen is designed for investigation of EAC initiation through a rounded, $\frac{1}{4}$ -inch (6.35 mm) diameter stress concentrator in the gauge without a pre-crack or machined notch. Cracking is promoted in the most susceptible S-L orientation, and an inductive displacement sensor fixed to a sample beam measures changes in deflection as the crack grows, for continuous monitoring of crack length during atmospheric corrosion testing. A finite element analysis (FEA) model was used to develop a compliance curve that is used to estimate crack length from sensor displacement. Estimates of stress intensity as a function of crack length were made using linear elastic fracture mechanics assumptions and implementing a FEA virtual crack closure technique.¹⁶ A compressive load was applied to deflect the sample beams together and induce a tensile stress in the outside stress concentrator so that crack growth propagates inward toward the sample beams. For this analysis, the load is assumed to be static.

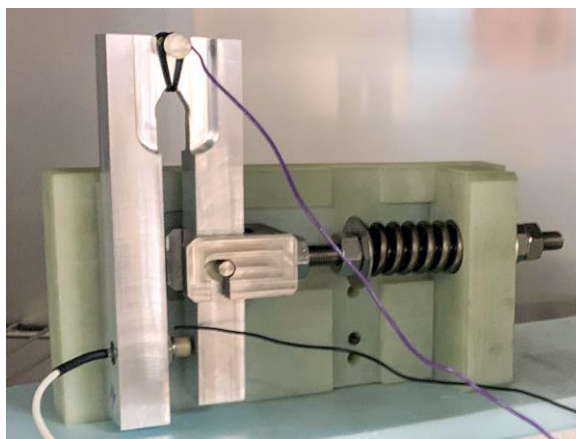


Figure 2. Test system with DCB and crevice former with electrical lead (left) and labelled sample diagram (right).

A SS316 crevice former was installed in the gauge region of the sample, over a known area of electrolyte support membrane. A galvanic couple was made between the DCB sample and the crevice former, through a laboratory potentiostat configured for periodic zero resistance ammeter measurements. The crevice former surface was masked except for the region in contact with the membrane in the gauge round of the DCB (Figure 3).