

Evaluation of Inhibited Organic Coating Protection Against Environmentally Assisted Cracking of High Strength Aluminum Alloys

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ABSTRACT

A test method is in development to assess aerospace coatings and their capacity to protect structures from environmental assisted cracking (EAC) initiation and propagation in corrosive atmospheres. EAC initiation and propagation is influenced by the complex interactions of load, environment, and alloy properties. These are explored and defined to produce a method that quantifies the crack initiation resistance provided by protective coatings for high strength aluminum alloy 7075-T651, enabling comparison between coatings. Accurate assessment of coating performance will reduce the risk associated with introducing new environmentally compliant coatings. Conventional immersion EAC testing is not well suited to study factors and interactions leading to atmospheric EAC because the bulk electrolyte conditions for immersion testing are different from those of a thin-film electrolyte. A controlled corrosive environment, unique test article geometry, static loading condition, and continuously monitoring sensor system are employed to measure onset and propagation of cracking under atmospheric conditions. Initial results demonstrate a strong dependence on inhibited primer type and galvanic coupling.

Key words: Environmentally assisted cracking, stress corrosion cracking, SCC, EAC, atmospheric corrosion, protective coatings, galvanic coupling

INTRODUCTION

High strength aluminum alloys, such as the 7xxx series, are susceptible to EAC under the right combinations of stress (applied or residual), environmental conditions, and material microstructure.

EAC presents a serious risk to vehicles, structures, and equipment operated in corrosive conditions. To reduce risk and improve safety, many types of organic corrosion inhibiting coatings for aluminum alloys have been produced and studied, and methods for evaluation of performance have been developed and standardized.¹⁻⁵ Typical methods of corrosion performance evaluation do not, however, incorporate testing under conditions with a mechanically stressed substrate, so no definite conclusions about protection against EAC can be made without drastic assumption.

Advancement in evaluation of coating effectiveness has been inhibited by a lack of EAC testing and sensing methods that are representative of the high-stress atmospheric corrosion conditions where EAC of marine and aerospace aluminum structures is most observed. Immersion testing, while simpler to control and characterize, is not necessarily representative of conditions that put aluminum structures at the highest risk for EAC. Oxygen, reactive halogens, and free radicals are likely to be present in higher concentrations within thin film electrolytes formed under atmospheric conditions, leading to a more aggressive stress corrosion cracking (SCC) environment. Exposure to humid air is known to facilitate increased hydrogen uptake and embrittlement.⁶⁻⁸ A method of coating evaluation in aggressive atmospheric environments will produce a more conservative understanding of the structural protection provided, than would immersion environments.

This work focuses on the development of a test system and method for evaluation of inhibited aerospace primers and their capacity to protect structures from static load EAC, or SCC, initiation and propagation in corrosive atmospheres representative of real-world conditions, as well as initial results comparing primer effectiveness depending on primer type and the presence of a galvanic couple. The test system is used to continuously monitor displacement of the arms of a primer coated double-cantilever beam (DCB) specimen to estimate crack length and growth rates over time. The primary metric used for comparison of coatings is crack initiation time, which shows a strong dependence on inhibitor type. Growth rates may also be valuable in evaluation of performance, especially in the presence of a galvanic couple.

EXPERIMENTAL APPROACH

This section presents a description of the instrumentation and test conditions used in static load EAC tests with primer coated double cantilever beam samples.

Static-load environmentally assisted cracking system (static-EAC system)

The static-EAC system was designed for loading of a DCB specimen to produce rising stress intensity crack growth (Figure 1). The DCB specimen is designed for investigation of EAC initiation through a rounded, 1/4-inch (6.35 mm) diameter, stress concentrator in the gage instead of a pre-manufactured crack or sharp notch. EAC is driven in the S-L orientation, and an inductive displacement sensor fixed to a DCB arm 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 can produce an estimate of crack length from sensor displacement. Estimations 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.⁹

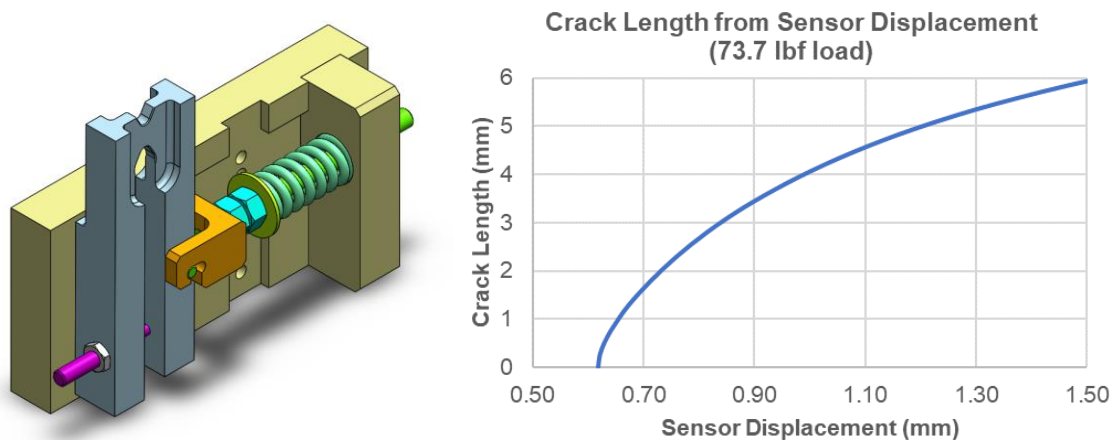


Figure 1. Schematic of instrumented DCB specimen and load frame (left). Displacement sensor (purple) monitors deflection to track crack growth. Plot of crack length as a function of sensor displacement produced using FEA developed compliance curve (right).

The FEA model was used to confirm that, with the 470 lbf/in (8.39 kg/mm) spring rate of the load frame spring, less than 2.5% of the starting load would be shed during cracking before the displacement sensor's range was exceeded and the test was complete. For the purposes of this testing, the load was considered static and was not monitored.

Selection of Test Conditions

The intent was to produce a test method that could demonstrate the effectiveness of primer prevention of EAC initiation and propagation in an atmospheric corrosion environment representative of real-world conditions. To do this, multiple test parameters and possible affects were considered, including temperature, relative humidity (RH), corrosive contaminant, contaminant application, stress, stress intensity, galvanic coupling and crevice conditions, coating defect geometry, and pre-test specimen conditioning. The selection and justification of each, as well as any supporting experimental work, is described following:

Relative Humidity and Temperature

Previous experimental work with AA7075-T651 under atmospheric conditions with a marine salt corrosive has demonstrated maximized growth rate at intermediate RH conditions near 55% RH.^{10,11} All tests were carried out with a static 55% RH hold, reached by drying after corrosive solution application, to maximize environment severity while maintaining a simple, repeatable test condition. An aggressive environment was desired primarily to improve test efficiency and produce conservative conclusions of primer effectiveness. Static temperature holds at 30 °C and 40 °C were both evaluated as reasonable temperatures that could be experienced in real-world environments. 40 °C was selected for most testing.

Corrosive Contaminant

Testing was performed using a commercially available marine salt* solution prepared with a 2.4 M chloride concentration, which makes results particularly relevant to structures that are exposed to a marine environment. Previous experimental work demonstrated significantly higher crack velocities for AA7075-T651 specimens exposed to a marine salt solution than those exposed to a sodium chloride solution, which could improve testing efficiency.¹⁰

* Instant Ocean Sea Salt