

Corrosion Severity Comparison of Three Beach Sites

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ABSTRACT

A comprehensive corrosion study was conducted over a period of twelve months at three exposure sites along the Florida coast: Daytona Beach, Kennedy Space Center (KSC), and the US Naval Research Laboratory, Key West. The long-term goal was to develop a better method to categorize the environmental severity of the exposure sites in terms of corrosion attack, which will aid in the design of accelerated laboratory testing and lifetime prediction for bare metal substrates in coastal environments. Measurements included site-specific weather parameters, mass loss of 1018 steel, and pitting characteristics of uncoated aluminum alloy (AA) 7075-T6. The results of this study yielded an overall ranking in severity of the three sites in terms of corrosion behavior for both steel and aluminum: KSC was the most severe, followed by Daytona Beach, which was slightly more severe than Key West. Pitting characteristics of the steel and aluminum substrates exhibited a strong positive correlation to cumulative salt deposition, but not to other weather parameters, such as exposure to various levels of relative humidity for various lengths of time. For AA7075-T6, lateral pit growth dominates over depth penetration, making mass loss determinations problematic and unreliable, whereas mass loss data for the 1018 steel provided clear indication of the increase in corrosion rate over time at the three exposure sites. However, analysis of the pitting on AA7075-T6 in terms of cross-sectional area and volume loss indicate a logarithmic increase over time for the three sites. These results reinforce the conclusion that while mass loss of steel coupon can be used as indicators of corrosion severity, mass loss for 7075-T6 aluminum alloy is an unreliable parameter to use for determining corrosion severity in the field.

Key words: Marine Corrosion, Aerospace, Bridges and Infrastructure

INTRODUCTION

The corrosion severity of an environment is important for both design and maintenance of infrastructure especially in marine and coastal environments. Corrosion can vary drastically depending on conditions such as temperature, humidity, salt loading, and rain events.¹ The interplay between these variables is quite complex so a variety of indirect techniques for quantifying corrosion severity are typically used. One common method is the determination of corrosion rate by measuring the mass loss of steel coupons exposed in the field.¹ Measuring the change in mass of the steel coupon as a result of the corrosion product being removed from the substrate can provide the rate of corrosion after a specific exposure time in the field.²

Other alloys of interest, particularly age hardenable aluminum alloys in the aerospace industry, are harder to characterize due to the non-uniform corrosion attack that these alloys exhibit. In the case of AA7075-T6, copper preferentially precipitates at the grain boundaries during heat treatment leading to an intermetallic galvanic couple with the adjacent aluminum.^{1,3,4} Corrosion will initiate at these sites and form pits or run along grain boundaries as intergranular corrosion (IGC). Corrosion is also initiated and accelerated by environmental contaminants, the most ubiquitous in marine and coastal environments being the chloride ion.⁵ This abundance, and being a small anion with high diffusivity and the ability to solubilize many metals, make chloride the most corrosive element in most marine and coastal environments.^{1,6-9}

The type of extremely localized attack seen on Al-Zn-Mg-Cu alloys means that mass loss measurements are inherently difficult due to the small damage area and morphology of attack.¹⁰ The quantification of any mass loss is usually at the lower limit of most laboratory analytical balances and can be easily masked by any uncleaned corrosion product. Mass loss determinations of AA2024-T3 and AA7075-T6 were attempted in this study, but due to the measured mass gain for several quarters as well as large standard deviations, corrosion rates based upon mass loss per unit area are not reported in this paper.

Mass loss determinations also do not provide much, if any, information about the pits themselves (morphology, depth, or volume) and are usually paired with cross-section analysis. It has been demonstrated that the line of sight measurements such as white light profilometry and laser microscopy can be much more effective than metallographic image analysis of cross-sectioned pitted specimens in measuring pit depths due to the fact that they can view a much larger portion of the surface and analyze thousands of pits with minimal effort.⁴ This ability to measure a large portion of the surface gives a better statistical representation of the attack on the specimen. With advances in laser microscopy and data processing, these techniques have become faster and more accurate, making them a more attractive option. Line of sight measurements cannot detect undercutting or IGC below the surface. Therefore, cross-section analysis may still be required in order to fully assess the pitting morphology.

Once the pitting is measured, there are many ways to quantitatively analyze material damage using laser microscopy. Several researchers have used optical microscopy on aluminum alloys in a similar method.¹²⁻¹⁴ Neeley found that it was most informative to look at the most severe pits, specifically the pit depth representing the 99th percentile; these values were found to best correlate with exposure duration in lab and outdoor environments.¹³ The findings described in this report attempt to build on some of these methods in order to rank the three beach sites in terms of their severity of corrosion on the bare metal substrates, and also attempts to analyze available weather data to determine what factors might lead to the most severe localized corrosion attack (i.e. pitting). Future work will be directed towards developing a more sophisticated method for comparing populations of pits on a metal surface and how that relates to corrosion degradation and weather conditions.

EXPERIMENTAL PROCEDURE

Coupon Preparation

Rollled sheet stock of 1018 steel (0.125" thick) and 7075-T6 aluminum (0.0625" thick) were cut into 3" x 0.5" samples, wet ground with isopropanol (IPA) sequentially through American Standards Institute (ANSI) 120, 400, and 600 grit silicon carbide (SiC) finish. After the final grinding, coupons were rinsed with IPA, dried with compressed nitrogen, and stored under a nitrogen atmosphere. Prior to mass determinations, the coupons were cleaned by immersion in boiling acetone and then boiling IPA for 5 seconds each. After being allowed to dry at ambient conditions for 30 minutes, the mass of each coupon was determined to five decimal places. This process was repeated three times, with the average mass taken as the initial deployed mass value of the coupon. After the mass determinations, the coupons were stored under nitrogen until the exposure cards were assembled for deployment. The coupons were mounted on a 4.0" x 4.375" fiber reinforced (FR) epoxy/glass laminate card, using two nylon fasteners with standoffs, one at each end, with an offset height of 0.5" from the card. The assembled cards were then vacuum-sealed in Mylar™ bags with oxygen absorber and desiccant packets to prevent corrosive attack during storage and transportation to the exposure sites: the Battelle Florida Materials Research Center in Daytona Beach (Daytona), the NASA Kennedy Space Center Beachside Atmospheric Corrosion Test Site (KSC), and the Naval Research Laboratory in Key West (Key West).

Deployment

The vacuum-packed samples were shipped to each site where they were opened just before deployment. At the beginning of the exposure period (February 2019 for Key West, May 2019 for KSC, and August 2019 for Daytona); all 12 sample cards were placed on an exposure rack facing south (except KSC which was facing east) angled 30 degrees from the horizontal rack, between 3-5 feet off the ground.

Retrieval

Three exposure cards with the steel and aluminum coupons were retrieved each quarter at each exposure site, resulting in replicates of 3, 6, 9, and 12 month cumulative exposures. Immediately after the card was taken off the exposure rack it was vacuum sealed in a Mylar™ bag with desiccant and oxygen absorber packets, and shipped back to UDRI for analysis.

Sample Cleaning

Aluminum Coupons - Coupons were cleaned according to ASTM G1-03, A1."Chemical Cleaning Procedures" Table A1.1 designation C.1.1 and C.1.2, Aluminum and Aluminum alloys.² A maximum of five coupons were placed in a beaker of solution containing 50 mL phosphoric acid, 20 g chromium trioxide in 1 L of deionized (DI) water and sonicated for five minutes. The coupon was then sonicated for five minutes in a beaker of 70% nitric acid. This two solution process of sonication was repeated resulting in a total cleaning time of twenty minutes. After sonication, each coupon was scrubbed with a stiff bristle brush while immersed in DI water, then rinsed in isopropanol and dried under a flowing air stream. The coupons were then allowed to further dry in air at ambient conditions for twenty minutes and mass values recorded to five decimal places. This process was repeated until the recorded mass had reached a constant value.

Steel Coupons - Coupons were cleaned according to ASTM G1-03, A1."Chemical Cleaning Procedures" Table A1.1 designation C.3.1, Iron and Steel. A maximum of five coupons were sonicated for five minutes in a solution containing 1 L hydrochloric acid, 20 g antimony trioxide, and 50 g stannous chloride. After sonication, each coupon was rinsed in DI water and scrubbed with a stiff bristle brush, dried under a flowing air stream and rinsed with IPA. The coupons were then dried in air at ambient conditions for twenty minutes and mass values recorded to five decimal places. This process was repeated until the recorded mass had reached a constant value.