

Corrosion of Open-Cell Aluminum Foams in Natural Seawater

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ABSTRACT

The microbiologically induced corrosion (MIC) behavior of open-cell aluminum foams (UNS A96101) was evaluated in sodium chloride solutions. Cast and heat treated UNS A96101 foams of relative densities in the 6-8% range and pore densities of 10, 20, and 40 pores per inch (PPI) were subjected to immersion tests under three different conditions. In one set of tests, coupons were subjected to immersion in simulated seawater (3.5 wt.% NaCl) under laboratory conditions in accordance with the ASTM G31-12a standard. Another set of experiments was performed by immersing foam test coupons in natural seawater off Terminal Island, Long Beach, California, for 7 and 14 days. An additional series of tests was conducted by immersing coupons in natural seawater aged in the laboratory. The surface of the foam coupons following each of the immersion tests was cleaned using an acid cleaning procedure that was developed expressly for quantifying foam corrosion. The microstructure and surface morphology were then characterized using scanning electron microscopy, coupled with energy dispersive spectroscopy. Microbial analysis of the natural seawater was also conducted.

Key words: Microbiologically induced corrosion, Open-Cell Aluminum Foams, Immersion Tests, UNS A96101-T6

INTRODUCTION

Microbiologically induced corrosion (MIC), or biocorrosion, is an electrochemical process in which microorganisms contribute to the initiation, facilitation, or acceleration of corrosion.¹ This form of corrosion is a prevalent issue in the marine industry due to the presence of microbes, and is an integral environmental factor for the evaluation of emerging metallic alloys used for near-coast applications.²

One of these emerging metallic alloys is open-cell aluminum foam. Open-cell aluminum foam exhibits a lightweight and porous structure as well as tailorable physical and mechanical properties due to their unique cell geometry.³ Commercially available 6000-series open-cell aluminum foams serve as a versatile solution to a variety of aerospace and marine needs. The most common fabrication method for this material is through an investment casting process, in which molten alloy is poured into a foam-shape mold imbedded in a compact pool of ceramic powders.⁴ As a consequence of investment casting, it has been observed that these foam materials have Al-Fe-Si intermetallics on the surface, subsequently leading to matrix-intermetallic interfacial attacks confirmed in localized corrosion studies.^{5,6} Recent studies on the corrosion behavior of open-cell aluminum 6101 foams have shown that their bulk

counterparts exhibit lower mass loss in simulated seawater environments.⁷ Given the growing commercial expansion of aluminum foam, it is crucial to extend investigations of its corrosion behavior in more realistic marine environments, particularly taking into consideration the influence of MIC.

The objective of this project was to characterize the microbially induced corrosion behavior of open cell aluminum foams (UNS A96101) as a function of pore density in natural seawater environments for marine applications. Normalized mass loss, corrosion morphologies, and bacterial characterization data were analyzed to determine the severity of biocorrosion. This project seeks to invigorate efforts in determining the feasibility of these novel materials for their optimization in marine applications.

EXPERIMENTAL PROCEDURE

Open-cell UNS A96101 foams and its bulk counterparts were utilized in this experiment. All coupons were subjected to a T6 heat treatment, consisting of quenching and artificial ageing to enhance mechanical strength.⁸ The heat treatment process was performed by the materials manufacturer. The composition of a nominal UNS A96101 alloy is listed in Table 1. The foams had pore densities of 10, 20 and 40 pores per inch (PPI) with constant relative densities in the 6-8% range. Foam specimens with dimensions of 0.30" by 0.25" by 0.75" and bulk specimens with dimensions of 0.50" by 0.50" by 0.25" were utilized for testing. The mass and dimensions of each specimen were recorded before testing. The surface area was determined by the manufacturer using the Brunauer-Emmet-Teller (BET) method.⁹ Pre-immersion specimens were ultrasonically cleaned in soapy water followed by acetone and deionized water for 3 minutes each. Bulk specimens were ground up to P600 grid (30 μ m) with SiC grit paper and cleaned using the same cleaning procedure used for the foam specimens.

Table 1: Chemical Composition of UNS A96101-T6 Alloy¹⁰

Element	Al	Si	Fe	Cu	Mn	Mg	Cr	Zn	B	Others
wt. %	Bal.	0.30-0.70	0.50	0.10	0.03	0.35-0.80	0.03	0.10	0.06	0.10

Bulk and foam samples were subjected to immersion testing in three seawater environments. These environments were: (i) 3.5 wt.% NaCl (simulated seawater) conducted in accordance with ASTM G31-12a¹¹ (ii) natural seawater at Terminal Island, Long Beach (fresh seawater), and (iii) seawater collected from Terminal Island, Long Beach, and stored in a sealed container at room temperature (static seawater). Immersion tests for (i) and (iii) were both performed at 35°C. Specimens were immersed for 7 and 14 days in each of the three environments. The pH, RDO, and conductivity of these three environments were recorded and are displayed in Table 2. Additionally, bacterial identification and count were performed with the Heterotrophic Plate Count (HPC) standard method for the examination of water and wastewater at LA Testing's Environmental Microbiological Laboratory to all environments prior to immersion testing.

To accurately determine mass of each sample after immersion testing, a chemical cleaning protocol was utilized to remove corrosion products from the metal surface. Post-corrosion samples were immersed in 68 to 70 wt.% nitric acid for 10 to 20 minutes until mass loss remained constant. Because of the varying surface area of the samples, mass loss was recorded by normalizing surface area.

As-received, post-corroded, and chemically cleaned test specimens were examined and characterized using the backscattered electron imaging (BEI) technique in a scanning electron microscope (SEM). Furthermore, local chemical compositions were obtained using energy dispersive spectroscopy (EDS).

RESULTS

Immersion testing of foam and bulk specimens were completed and the corrosion behavior in the three testing environments were observed and recorded. Figures 1 and 2 show the BEI micrographs for as-

received UNS A96101 foam subjected to a T6 heat treatment process. Lighter colored dendritic structures can be observed on the surface, which is characteristic of Al-Fe-Si intermetallic phases.¹² The composition of these phases (Fe, Si, Al) is shown through EDS analysis as shown in Figure 3. The presence of these intermetallic phases plays an integral role on the corrosion behavior of the material, as it has shown to be a site for corrosion initiation.⁷

The mass loss normalized by the unit area of UNS A96101-T6 bulk and foam specimens are depicted in Figures 4 and 5. The mass loss values within each environment are shown in Table 3. On average, mass loss was highest among all samples in the fresh seawater environment, and mass loss was lowest in the simulated seawater environment. Additionally, bulk alloy exhibited the lowest mass loss for all three marine environments. This trend is consistent with previous immersion studies.⁷ The mass loss of the foam specimens in any of the immersion environments exhibited increases as the pore density and surface area increase.

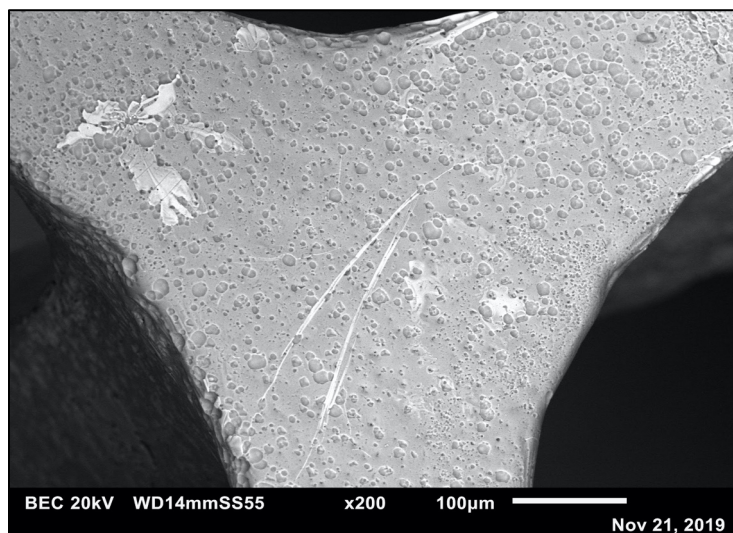


Figure 1: Backscattered electron micrograph of junction of as-received 40 PPI UNS96101-T6 Foam (200x)

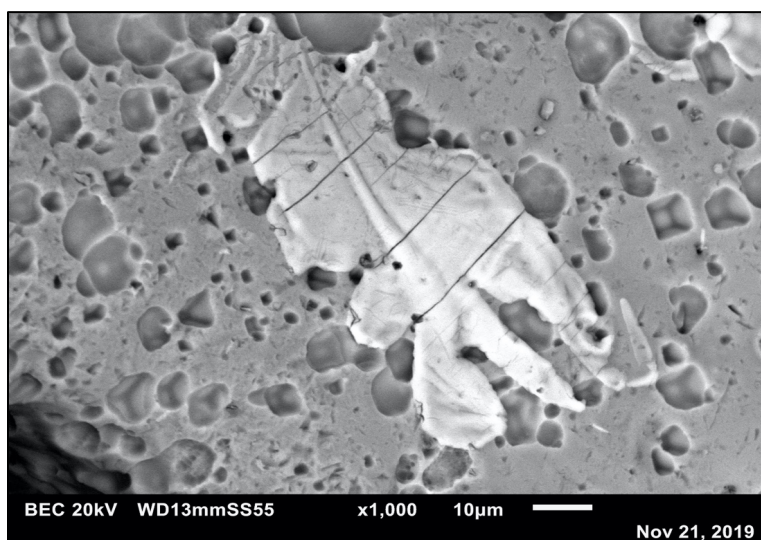


Figure 2: Backscattered electron micrograph of a strut of as-received 40 PPI UNS96101-T6 Foam (1000x)