Development of semi-elliptical surface cracks in lightly sensitized Al-Mg alloys

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Al-Mg alloys containing more than 3 wt. % Mg are susceptible to intergranular stress corrosion cracking when exposed to elevated temperatures (≥ 50 °C) for a sufficient length of time in corrosive environments [1], which may ultimately impose limits on the use of these alloys in naval systems. Recently, we have developed deterministic codes that incorporate models and algorithms for describing the electrochemistry of marine environments and the growth of stress corrosion cracks of lightly sensitized Al-Mg alloys via the Coupled Environment Fracture Model, CEFM. The importance of the properties of the external environment, such as solution conductivity, electrochemical potential (ECP), flow velocity, and the kinetics of the cathodic reactions on the surfaces external to the crack has been confirmed [2]. Surface stress corrosion cracks are commonly semi-elliptical in form, suggesting a variation in the crack growth rate (CGR) along the crack front, with the CGR being greatest at the intersection of the crack with the external surface (thereby defining the major axis) and least at the center (thereby defining the minor axis). This was confirmed by the dependence of the CGR on the electrochemical crack length (ECL), which is the least resistive path for current flow through the in-crack environment between the local crack front and the external surface. This dependence arises from the existence of an *IR* potential drop down the crack enclave, resulting from the flow of the coupling current, which reduces the potential drop across the external surface that is available for driving oxygen reduction or hydrogen evolution. Thus, the oxygen reduction reaction rate is reduced and so is the coupling current, thereby leading to a decrease in the CGR with increasing the ECL, since the CGR is linearly related to the coupling current. Our analysis of the shape of surface cracks in sensitized Type 304 SS in Boiling Water Reactor coolant environments using the CEFM offered a better explanation for the development of semi-elliptical cracks than that provided by fracture mechanics alone [3]. It is our postulate that the same basic mechanism is responsible for the development of semi-elliptical surface cracks in lightly sensitized aluminum alloys in marine environment, as shown in Figure 1. In this paper, we explore the evolution of the surface crack shape upon ECP, solution conductivity, flow velocity, and multiplier of the standard exchange current density for IGSCC in lightly sensitized Al-Mg alloy in marine applications. In predicting the shape evolution of a surface crack, the variation of local stress intensity factor, K_I, along the crack front is also considered in this work, since crack advance changes the K_I along the crack front with time.

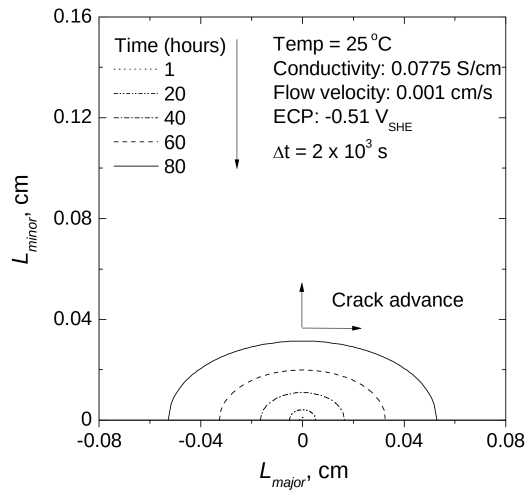

Figure 1. Predicted crack shape with respect to elapsed time in AA5083-H321 in 3.5 wt.% NaCl solution at 25 °C. L_{major} and L_{minor} represent the crack lengths along and perpendicular to the surface, respectively. Note that the crack nucleus is assumed to be semi-circular of radius 10 μm.

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[2] S.-K. Lee, P. Lv, and D. D. Macdonald, “Customization of the CEFM for Predicting Stress Corrosion Cracking in Lightly Sensitized Al-Mg Alloys in Marine Applications”, unpublished paper.

[3] D. Kramer, S.-K. Lee, and D. D. Macdonald, “On the Shape of Stress Corrosion Cracks in Water-Cooled Nuclear Power Reactor Piping.”, 222nd ECS meeting, Honolulu, Hawaii (2012).