

Modeling Galvanic Corrosion

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Abstract

Galvanic corrosion is an electrochemical process that occurs when at least two dissimilar metals (electrodes) are in electrical contact with one another, and are in a conducting environment known as an electrolyte [1]. Electrochemical reactions are chemical reactions that involve release and uptake of electrons from/to an external circuit. One electrode acts predominantly as anode (electron and cation producing) and is the component of the galvanic couple that undergoes material dissolution while the other acts predominantly as cathode and is the site where a cathodic (electron and anion consuming) reaction takes place. The electrons produced by the anodic reaction are exactly used up by anions at the cathode by the cathodic reaction (see Figure 1).

Galvanic corrosion is particularly prevalent in marine applications because seawater acts as an electrolyte. The amount and rate of dissolution of the anode material is directly related to the electrochemical potential distribution at the anode-electrolyte interface. Assuming a stagnant electrolyte, the equation governing the distribution of electrochemical potential inside it is obtained combining the equation conservation of charge with the constitutive equation relating the electric field distribution to the electrochemical potential gradient. The result is Laplace's equation. The equation must then be solved subject to appropriate boundary conditions. Two types of boundary conditions are applicable in galvanic corrosion situation. At those interfaces where there is no charge transport, a homogeneous Neumann condition is imposed while at electrode-electrolyte interfaces, experimentally determined current-potential relationships are required. The most general current-potential relationship is the Butler-Volmer equation describing the electrochemical kinetics of anodic and cathodic reactions at the specific electrode-electrolyte interface.

The coefficient form PDE model in COMSOL Multiphysics® has been used to develop a broad variety of models of galvanic corrosion systems. A simple planar model similar to the one shown on figure 1 was used for validation purposes [2]. Figure 2 shows the computed potential distribution for the input data given in [2]. The rate of change of potential along the electrode surfaces is rather large yet continuous in the vicinity of the junction between the two dissimilar metals while the variation is much shallower along the free surface of the electrolyte. These results are in excellent agreement with results previously obtained using a finite difference method [2]. Figure 3 shows the computed current density along the interface between the electrodes and the electrolyte (left hand side). Cathodic current is shown with negative sign and anodic current is positive. The large values of current density at the anode-electrolyte interface

can be converted to anode dissolution rate through the use of Faraday's law and the result is shown on the right hand side of figure 3. These results can thus be used to estimate the expected dissolution rate under galvanic corrosion conditions. Several other models have been developed to explore the behavior of various galvanic corrosion configurations and full details can be found in the Master's Project report on which this paper is based [3].

Reference

- [1] Zhang, X. G. (2011). Galvanic Corrosion. In Uhlig's Corrosion Handbook (Third ed., pp. 123-143). John Wiley & Sons, Inc.
- [2] Doig, P., & Flewitt, P. E. (1979). A Finite Difference Numerical Analysis of Galvanic Corrosion for Semi-Infinite Linear Coplanar Electrodes. Journal of The Electrochemical Society , 126 (12), 2057-2063.
- [3] Megan Elizabeth Turner, Finite Element Modeling of Galvanic Corrosion of Metals, Mechanical Engineering Master's Project, Rensselaer at Hartford, December 2012.

Figures used in the abstract

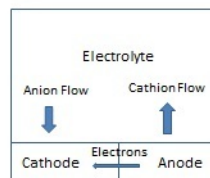


Figure 1: Schematic representation of electrochemical phenomena in a galvanic junction.

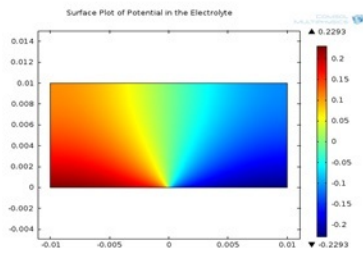


Figure 2: Computed potential field in a galvanic junction.

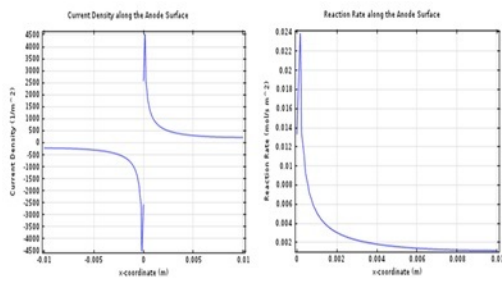


Figure 3: Computed current density along the interface between the electrodes and the electrolyte (left) and anode dissolution rate (right)