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Validated numerical modelling of galvanic corrosion for couples: Magnesium alloy (AE44)–mild steel and AE44–aluminium alloy (AA6063) in brine solution

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ABSTRACT

A numerical model is presented in this work that predicts the corrosion rate of a galvanic couple. The model is capable of tracking moving boundary of the corroding constituent of the couple. The corrosion rates obtained from the model are compared with those estimated from mixed potential theory and two experimental techniques, namely Scanning Vibrating Electrode Technique (SVET) and immersion technique. The corrosion rates predicted using the model are in good agreement with those estimated from the experimental techniques for magnesium alloy AE44–mild steel couple, however, the model under predicts the corrosion rate for AE44–aluminium alloy AA6063 couple.

1. Introduction

Galvanic corrosion can occur when two dissimilar metallic alloys are in electrical contact with each other for electron transport and are exposed to a conductive environment such as salt water that provides a medium for ionic flow. A material with a lower free corrosion potential (E_{corr}) in a galvanic couple becomes more active and corrodes preferentially. Corrosion severity of a galvanic couple depends upon various factors such as E_{corr} difference between the dissimilar metal alloys, polarization behaviour of individual alloys, anode to cathode area ratio, electrolyte conductivity, distance between the dissimilar metal alloys, etc. [1]. The free corrosion potential of individual alloys in flowing sea water at 2.4–4 m s^{-1} velocity at 5–30 °C temperature is represented in Fig. 1, which is commonly known as the galvanic series [1]. It can be seen from the galvanic series in Fig. 1, that magnesium sits at the bottom left corner and exhibits the lowest free corrosion potential [1]. Hence, magnesium is prone to high corrosion activity and corrodes preferentially when coupled with other common structural materials such as aluminium alloys or mild steel. It should be noted that the galvanic series ranks individual alloys exposed to sea salt solution on the basis of the individual free corrosion potential they exhibit and does not account for the galvanic interaction. Hack [2] reported that both metals involved in a galvanic couple should be considered in order to predict the galvanic corrosion rate. In this work, we address the challenge of estimating the corrosion behaviour of a galvanic couple from the corrosion behaviour of the individual alloys involved in the couple. The galvanic series provides qualitative information about the corrosion severity based on the free corrosion potentials of the individual alloys, whereas in this work corrosion severity is quantified by means of a numerical model which considers the polarization behaviour of the individual alloys and provides the corrosion rate of the galvanic couple.

The electric potential and the current density of the galvanic couple can be estimated from the polarization behaviour of the constituent individual alloys of equal area ratio by overlaying their polarization curves, as shown in Fig. 2 for a representative couple. The point of intersection of anodic branch of an alloy with a lower E_{corr} and cathodic branch of an alloy with a higher E_{corr} represents the corrosion potential and the current density of the galvanic couple. This method of estimating the corrosion rate of the galvanic couple is referred to as mixed potential theory hereafter. Corrosion rate prediction obtained using this method is fairly accurate when E_{corr} of the constituent alloys are more than approximately 120 mV apart depending on the slopes of the polarization curves, as reported by Hack [2]. Maddela et al. [3] have previously used the mixed potential theory approach in order to investigate galvanic corrosion of various magnesium–aluminium couples using sectional electrode technique. In this work, we focus on magnesium alloy AE44, aluminium alloy AA6063 and mild steel, which are of interest in automobile industry. The galvanic couples considered here are AE44–mild steel, and AE44–AA6063.

There is an extensive amount of analytical work reported in literature to investigate galvanic corrosion. Waber et al. [4–6] have used linear and equal corrosion kinetics (equal polarization parameter) for semi-infinite and parallel anode and cathode surfaces.

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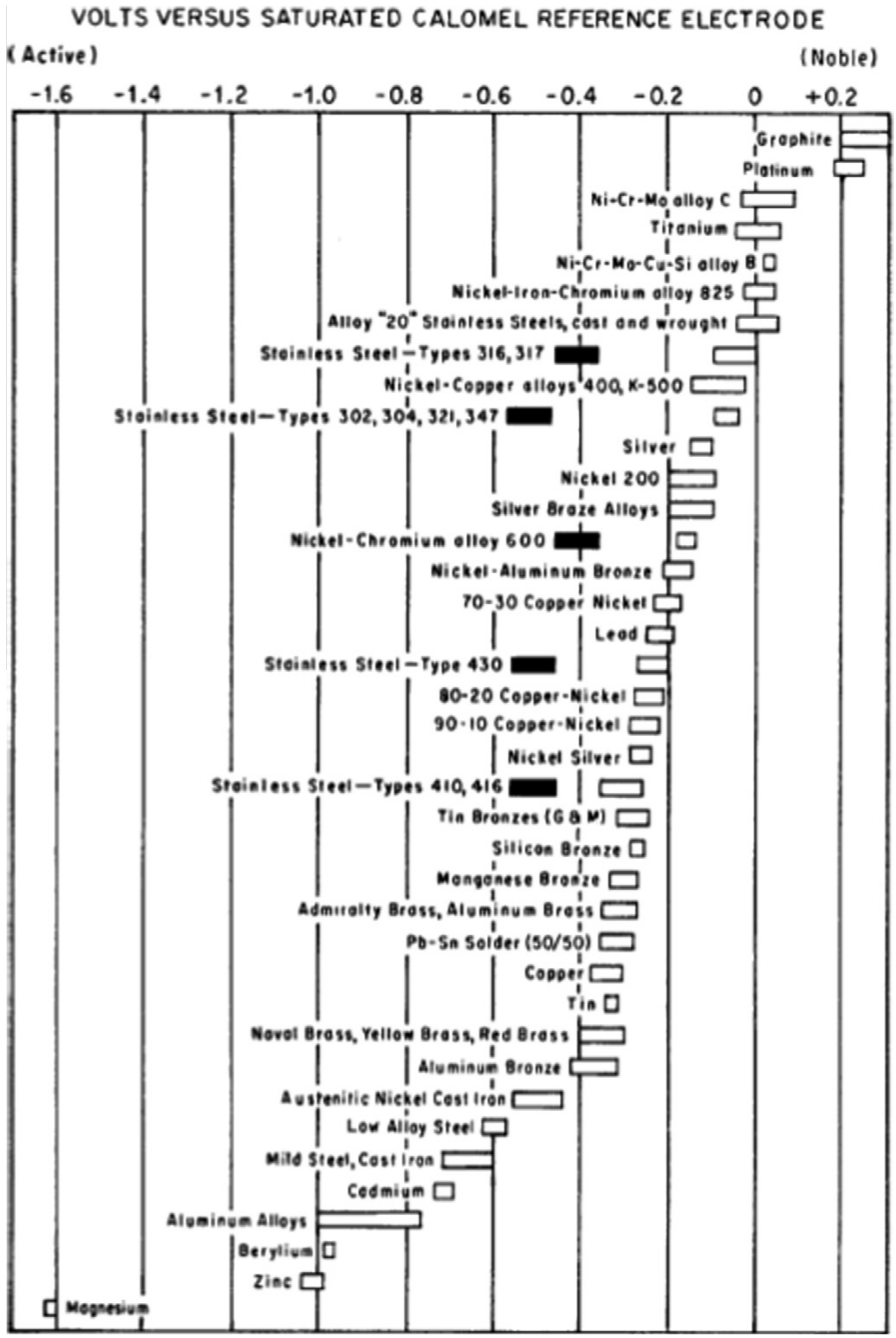

Fig. 1. Galvanic series where metals are ranked on the basis of the potential they exhibit in seawater at 2.4–4 m s^{-1} for 5–15 days at 5–30 °C, as taken from ASTM G82 [1].

This work has been extended by Kennard and Waber [7], by using unequal and linear polarization parameters for anode and cathode surfaces and McCafferty [8] has applied these unequal and linear polarization parameters to circular systems. Galvanic corrosion over semi-infinite coplanar surfaces has been investigated by Verbrugge [9] using the conformal mapping technique. Recently, Song [10] has developed an analytical approach to investigate galvanic corrosion in some practical cases such as steel–aluminium joint exposed to bio-fuel, galvanic couple with a passive spacer and a scratched organic coating. A numerical model solving the Laplace and Nernst-Planck equations for a galvanic couple comprised of Al and Al4%Cu, has been reported by Murer et al. [11]. They have compared model predictions for current density with those obtained using Scanning Vibrating Electrode Technique (SVET). Most of the numerical modelling work reported in the literature [12–16] employs boundary element method based commercial software called BEASY. All the above mentioned work considers stationary anode and cathode surfaces. During galvanic corrosion, however,