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3D computer simulation of the influence of microstructure on the cut edge corrosion behaviour of a zinc aluminium alloy galvanized steel

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Abstract

Recently, experimental work has been reported that demonstrates the effects of microstructural variations within Zn–Al Galfan type coatings on the corrosion behaviour of cut-edge material, i.e. those cases where both the underlying steel and the organic coated Galfan layer are simultaneously exposed to a corrosive environment [J. Elvins, J.A. Spittle, D.A. Worsley, Microstructural changes in zinc aluminium alloy galvanising as a function of processing parameters and their influence on corrosion, Corros. Sci. 47 (11) (2005) 2740–2759]. In this paper a finite difference numerical model of localized corrosion has been applied in an attempt to simulate this type of corrosion. Results from the model are compared to experimental observations.

Keywords: A. Galfan coatings; B. Modelling; B. Finite difference; C. Localized corrosion; C. Microstructure

1. Introduction

Protection of steel used in the construction industry against the detrimental effects of corrosion is an area of significant engineering importance. Corrosion effects have a

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negative impact on material properties leading to unwanted economic consequences. Manufacturing methods that limit the deleterious influence of physicochemical processes on the world's durable goods and infrastructure often involve the use of protective coatings. Metallic coatings are used in the protection of iron and steel, traditionally applied by hot-dip methods. The capacity of zinc to afford barrier and cathodic protection as a steel coating has seen the wide-spread use of galvanized products [2]. In the construction industry there is an increasing demand for the improvement of corrosion resistance of organically coated steels, typically used in cladding and roofing of buildings.

Much interest concerns the development of galvanizing coatings containing ~4.5 wt.% Al. Coating alloys of this type have been seen to exhibit greater ductility and superior corrosion resistance than conventional galvanizing alloy systems (galvanized steels suffer larger Zn dissolution rates [3]) some of which include small aluminium additions in order to prevent large scale intermetallic formation during fabrication [1–5]. The 4.5 wt.% Al zinc alloy, often known as Galfan, is commonly applied to steel and used as the substrate for organically coated steel products, used as profiled cladding in building solutions. In such applications the product is known to be susceptible to localized degradation at cut-edges leading to delamination of organic coating and degradation of the metallic coating remaining exposed.

2. Numerical model

The numerical model comprises field-based calculations for electrical potential and diffusion/migration coupled to standard electrochemical equations [6,7]. A brief overview of the model is provided below.

The model uses an orthogonal structured computational grid to represent both the solid and liquid electrolyte in each simulation of dimensions $nx \times ny \times nz$. Differential equations employed by the model are approximated via straightforward finite difference methods. The model permits non-uniform nodal spacings in the x, y and z directions. Each cell in the grid possesses an integer value identifying the site as either electrolyte or solid. Electrolyte sites are then also defined in terms of concentration (c, mol dm^{-3}), electrical potential (ϕ, V), current density vector (i_x, i_y, i_z, A m^{-2}), volume fraction of the cell occupied by corrosion product (p) and the volume fraction of the cell that has already been corroded away. Solid sites contain information of composition and volume fraction corroded (f).

2.1. A first order model of corrosion

Attempting to simulate the localized corrosion of zinc alloy steel coatings with a physically based numerical model inevitably requires simplifying assumptions to be made. A first order model that deals with the evolution and movement of a single ionic concentration (increases of which are brought about by anodic dissolution) has been used. The model assumes that the Zn^{2+} rapidly undergoes hydrolysis to produce solid zinc hydroxide via

$$Zn^{2+}_{(aq)} + H_2O_{(l)} \rightarrow Zn(OH)^{+}_{(aq)} + H^{+} \quad (1)$$

$$Zn(OH)^{+}_{(aq)} + H_2O_{(l)} \rightarrow Zn(OH)_{2(s)} + H^{+} \quad (2)$$