Physical and mathematical modelling of pitting corrosion

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Physical and mathematical modelling of pitting corrosion

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Abstract – **The study of corrosion (especially pitting corrosion) is complicated by the highly random nature and slow rates of the natural corrosion process. We present an experimental setup for enabling accelerated corrosion, procedures for its use to accelerate physical modelling of pitting corrosion, and results of associated mathematical modelling.**

Keywords – accelerated corrosion, pitting corrosion, physical corrosion modelling, Monte-Carlo corrosion modelling.

I. INTRODUCTION

Corrosion causes damage to various structures, machinery and goods. Its cost in the US alone was estimated at 276 BUSD in 2002 [1]. Corrosion is a highly random process; therefore, the development of corrosion monitoring instrumentation and procedures requires a good understanding of how the corroded parts change over time and respond to interrogation (*e.g.*, ultrasonic signals). However, the observed in the UK average rates of natural corrosion exceed 0.1 mm/year only in some industrial atmospheres [2], making study of natural corrosion very time consuming. In this paper, we discuss how pitting corrosion can be modelled both physically and mathematically within short time frames.

II. PHYSICAL MODELLING OF PITTING CORROSION

We developed a setup to accelerate natural corrosion by applying a constant electrical current, which eroded the cylindrical iron bar anode in a typical electroplating setup (fig.1) [3]. The sides of the bar were protected from corrosion by applying lacquer and heat shrink tubing (fig.2). Clear erosion of the anode and accumulation of extra iron on the cathode were observed after the 2.5 hour experiment (fig.3). The anode lost over 1% of its weight (fig.4) or over 1 mm of its length, confirming the suitability of the setup for studying accelerated physical modelling of uniform corrosion [3].

Pitting corrosion is a form of extremely localised corrosion that leads to the creation of small holes in the metal. We modelled it by covering the corroding surface with a protection layer. Corrosion was still able to erode the anode, but this time it progressed non-uniformly only through some weaker spots in the protection layer, even though the protection layer was notionally uniform [4]. This experimentally observed result needed some further explanation.

III. MATHEMATICAL MODELLING OF PITTING CORROSION

We modelled corrosion by representing the metal sample as a 2D body consisting of identical square cells. We assumed that if a cell is adjacent to a corroded cell, a probability exists that the former will also corrode. This probability was multiplied by the number of corroded cells that surrounded the metal cell in question. At every Monte-Carlo modelling step, uniformly distributed random numbers [0,1] were generated for all the cells. If the number for a given cell was lower than the total probability of corrosion, the cell was marked as a corroded one.

The modelling results, obtained using a custom MATLAB script, are presented in figs.5 and 6 for various corrosion scenarios (no protection layer and protection layer with defects) and two cell corrosion probabilities. The results showed that the erosion rate is roughly proportional to the corrosion probability and that imperfections of the protection layer caused pits.

IV. CONCLUSIONS

Accelerated physical modelling of pitting corrosion can be achieved by covering the corroding surface with a notionally uniform protective coating and forcing electrical current through it. Monte-Carlo mathematical modelling confirms validity of this approach.

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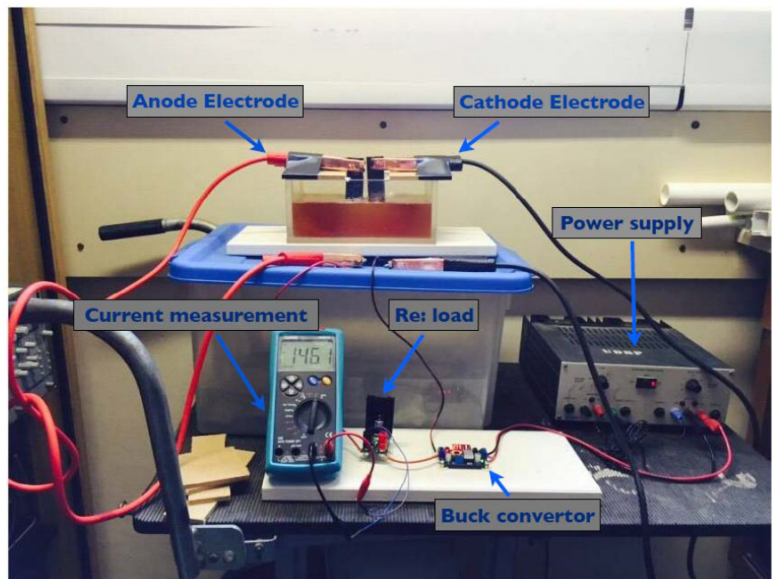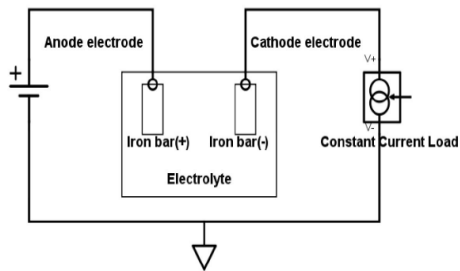
Fig.1. The experimental setup

Fig.2. Preparation of the corroding samples: original iron bar, bar coated with PCB lacquer, coated bar with set heat shrink tubing
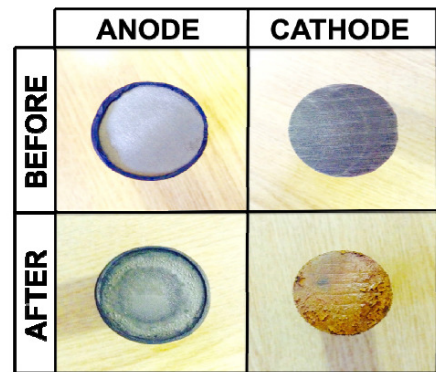

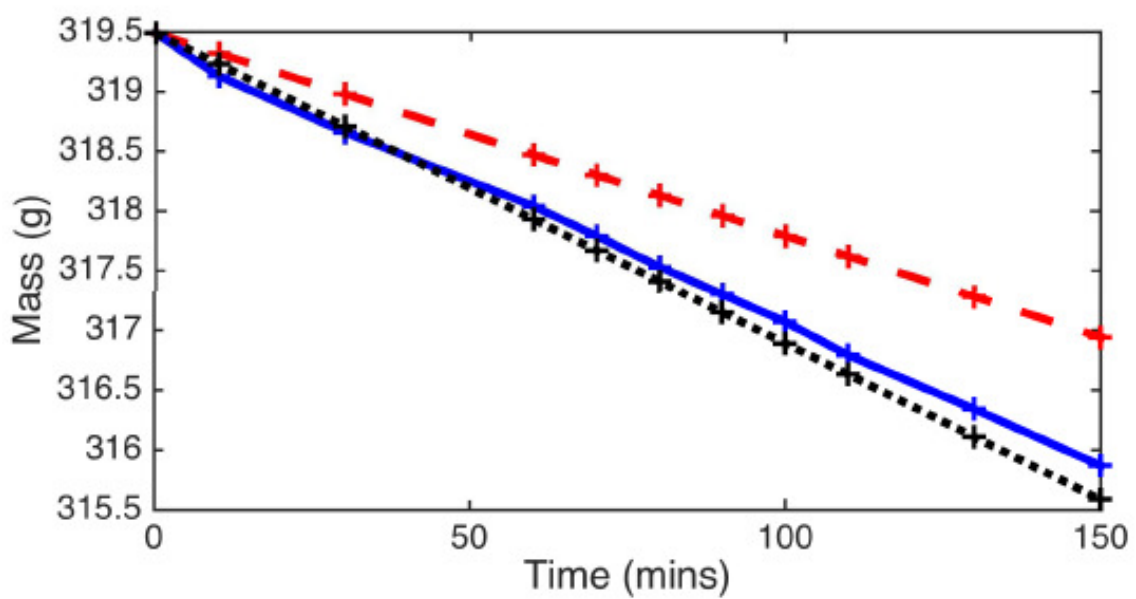Fig.3. Surfaces of the electrodes before and after the experiment

Fig.4 Measured (solid line) and expected (dotted lines for Fe^{2+} and dashed lines for Fe^{3+}) weight of the corroded sample versus the accumulated corrosion time.
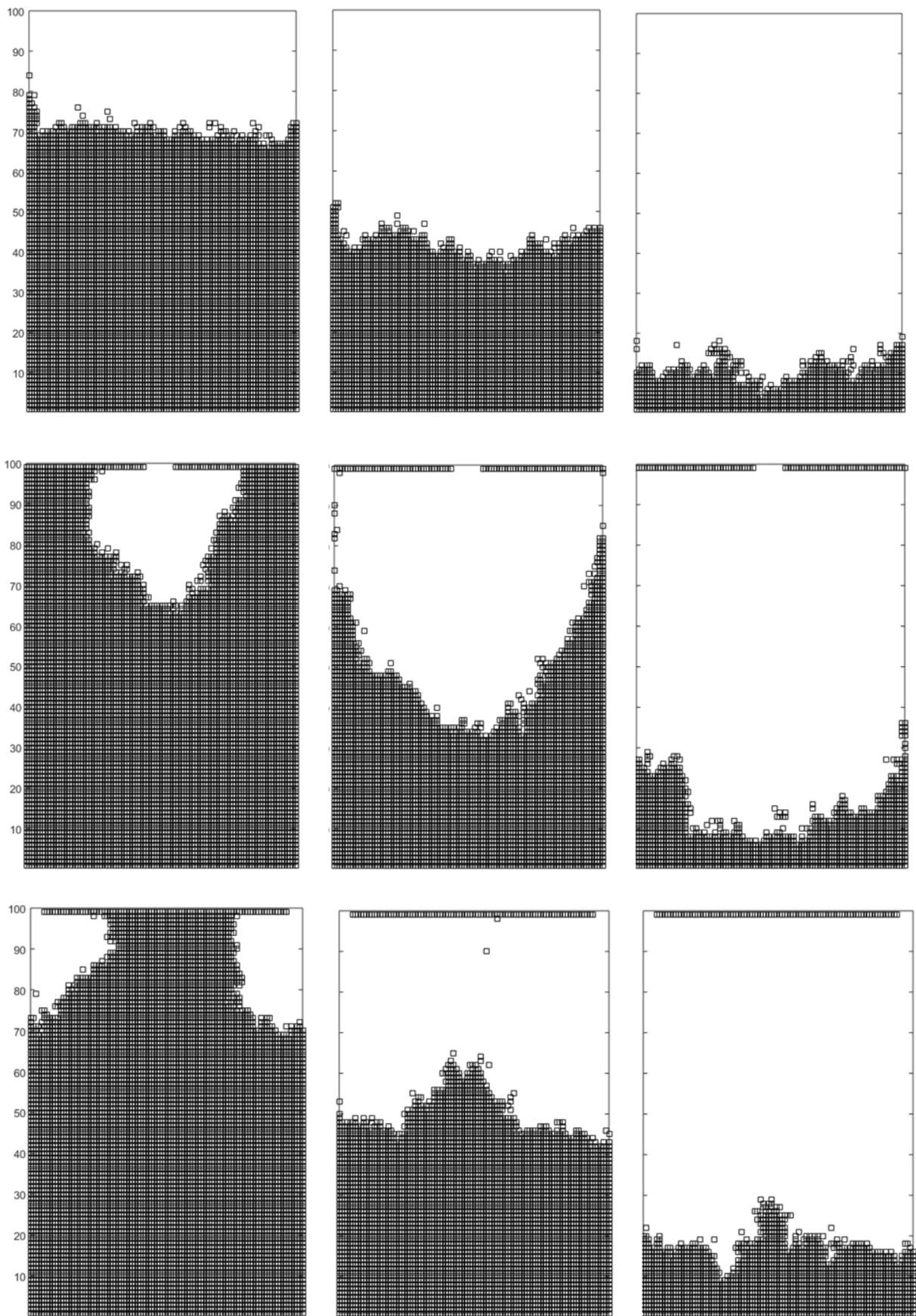
Fig.5. Mathematical modelling of corrosion for single neighbour corrosion probability of 0.04
(upper graphs - uniform corrosion of an untreated sample, centre graphs - corrosion via a small scratch in the protection layer, lower graphs - corrosion via the sides of the protection layer; left, centre and right graphs - corrosion after 100, 200 and 300 simulation steps, respectively)
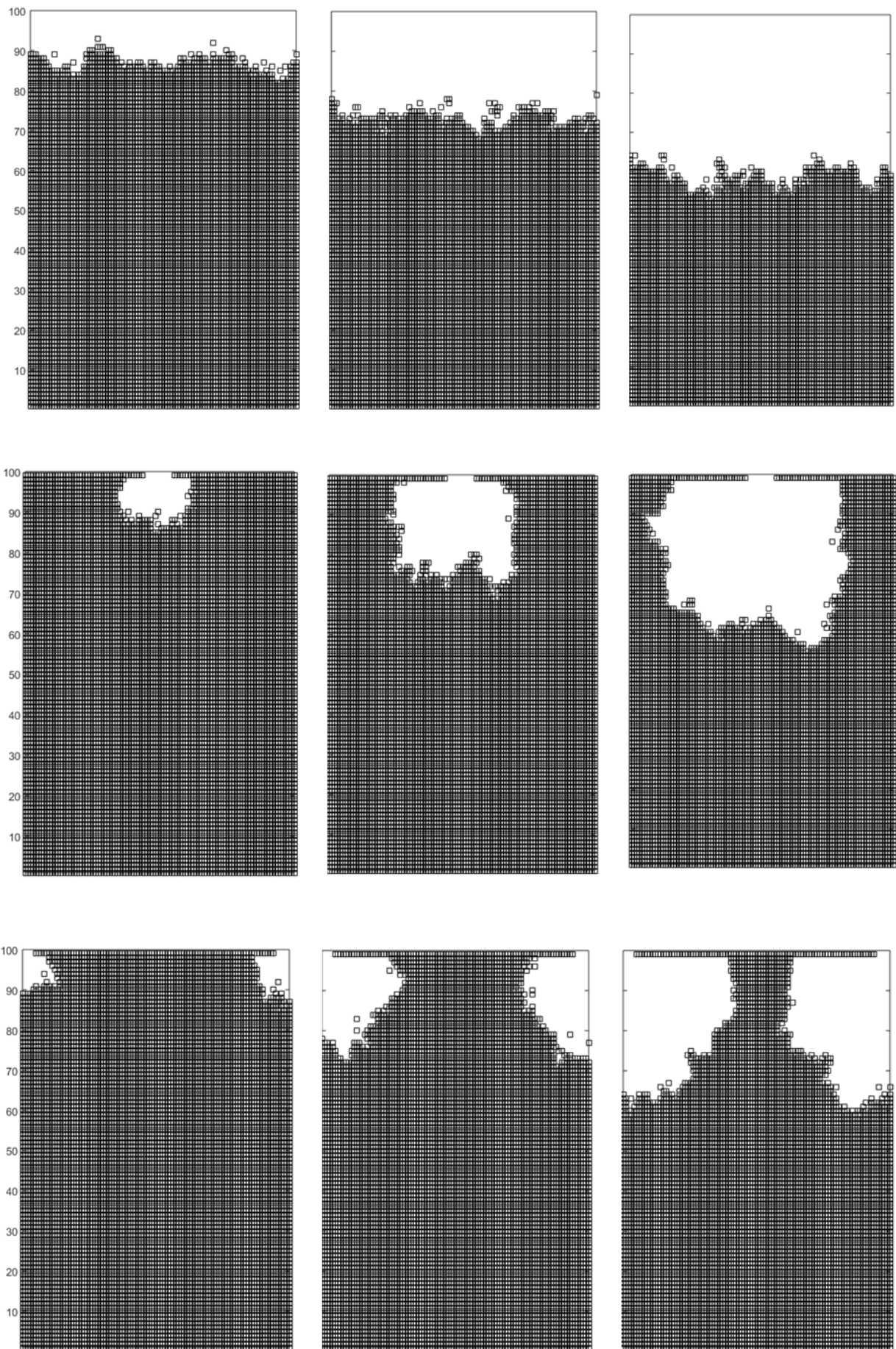
Fig.6. Mathematical modelling of corrosion for single neighbour corrosion probability of 0.02
(upper graphs - uniform corrosion of an untreated sample, centre graphs - corrosion via a small scratch in the protection layer, lower graphs -
corrosion via the sides of the protection layer; left, centre and right graphs - corrosion after 100, 200 and 300 simulation steps, respectively)