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An investigation of the effect of a magnetic field on the phosphate conversion coating formed on magnesium alloy

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ABSTRACT

In this paper, the influence of the magnetic field on the phosphate conversion coating formed on magnesium alloy has been studied by scanning ion selective electrode technique (SIET), X-rays phase-contrast radiography, scanning electron microscopy (SEM) and atomic force microscopy (AFM). The results show that the superposition of a magnetic field during the phosphate conversion coating process can promote the generation of small hydrogen gas bubbles and accelerate their desorption. In addition, irrespective of the microstructure of the AZ91D magnesium alloy, it was found that the Mg^{2+} cations were distributed comparatively uniformly. A uniform smooth phosphate conversion coating could be obtained by immersion in the treatment solution when a magnetic field was applied perpendicular to the magnesium alloy. It may be expected to use magnetic field to control the formation of phosphate conversion coating on magnesium alloy.

1. Introduction

Phosphate conversion coatings are a promising alternative to chromate conversion coatings for corrosion protection of magnesium alloys [1,2], and have recently attracted considerable attention because metal phosphates are insolubility and do not include environmentally harmful elements [3,4]. However, the quality of these phosphate conversion coatings is not significantly improved because there are some intrinsic micro defects such as cracks and pores in these coatings [5,6]. Magnetic field, as a controllable method, has been adopted in the conversion coating process. Some researchers have reported changes in coating structure when a magnetic field was applied [7,8]. In our previous work, a defect-free phosphate conversion coating was produced on magnesium alloy when a perpendicular magnetic field was applied and its corrosion protection ability was sufficiently improved [9]. In fact, the formation of conversion coating on magnesium alloy is associated with magnesium dissolution followed by hydrolysis of the Mg^{2+} formed [10,11] and the evolution of hydrogen bubbles. The Mg^{2+} cation is a constituent of the multi-elements conversion coating [12,13] and an essential cation involved in the conversion coating processes. It is obvious that the formation of hydrogen bubbles on the surface of magnesium alloy shields and blocks the conversion coating growth sites. Although it is known that the behaviour of metal cations [14,15] and the gas bubble evolution [16,17] are affected by a magnetic field due to magnetohydrodynamic (MHD) effects, the influence of the magnetic field on the Mg^{2+} cation behaviour and the hydrogen bubble evolution during the formation process of phosphate conversion coatings has never been reported.

The objective of the present work was to investigate Mg^{2+} cation distribution, hydrogen bubble evolution, the topography and morphology of conversion coating depend on the amplitude of magnetic field. What we know so far, our work is the first one which considers Mg^{2+} cation behaviour and the hydrogen bubble evolution during conversion coating formation and their influence on the quality of phosphate conversion coating.

2. Experimental

Semi solid cast AZ91D magnesium alloy (nominal composition: 9% Al, 1% Zn, 0.3% Mn, and balance Mg) was cut into coupons. The treatment solution contained 40 g/L $KMnO_4$, 150 g/L K_2HPO_4, and 20 g/L H_3PO_4. A magnetic field, which was generated by a resistive tube magnet, was superposed during the SIET measurements and the X-ray phase-contrast imaging experiments. It was found that the perpendicular magnetic field is more effective than the parallel field in enhancing desorption of hydrogen bubbles from the surface of magnesium alloy, therefore the magnetic field is applied

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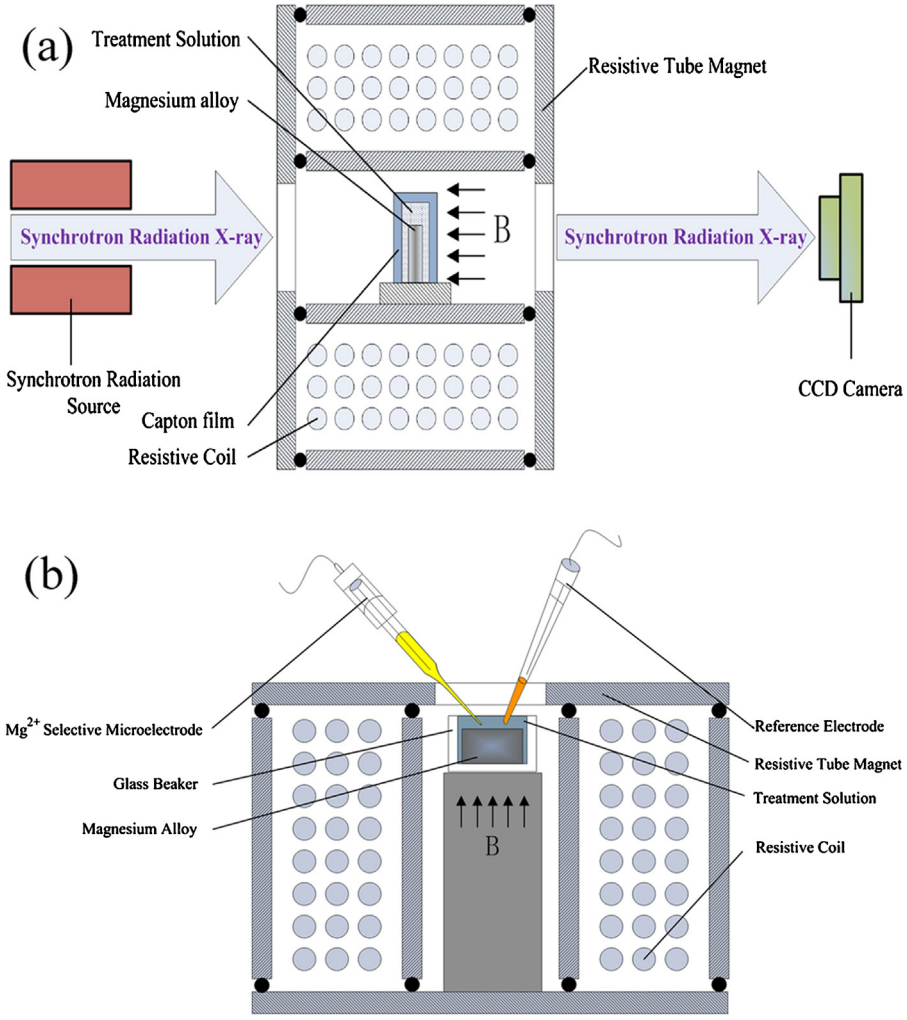

Fig. 1. Schematic diagram of the magnetic field configuration of X-ray phase-contrast imaging experiment (a) and Mg^{2+} cation concentration measurement (b).

perpendicular to the surface of the magnesium alloy. The schematic diagram of the magnetic field configuration of X-ray phase-contrast imaging experiment and Mg^{2+} cation concentration measurement is shown in Fig. 1. The resistive tube magnet can produce a magnetic flux density uniformly distributed across the surface of the magnesium alloy. The polarity of the magnetic field can be control by the direction of the flow of current through the coil and the magnetic flux density can be regulated continuously ranging from 0 T to 0.8 T. A sample was successively polished with waterproof abrasive paper from 360 grits down to 2000 grits and finally with 1 μm diamond paste, degreased with ethanol in ultrasonic bath for 10 min, rinsed with distilled water and subsequently dried at room temperature. The polished sample was immersed into the treatment solution to monitor the Mg^{2+} cation concentration during conversion coating formation without a magnetic field. Then, the same sample was polished, using the same procedure described above, to measure the Mg^{2+} cation concentration in each experiment with a magnetic field. For the X-ray phase-contrast imaging experiments, three slices were cut off from the same semi solid cast AZ91D magnesium alloy, polished to 30 μm thickness in the same way, and were fixed into the experimental cell to observe the hydrogen bubble evolution without and with magnetic fields. Note that because the samples were taken from the same semi solid cast AZ91D magnesium alloy and polished by the same procedure, the effects of surface structure and morphology of magnesium alloy on hydrogen bubble evolution and conversion coating formation can be significantly reduced. Accordingly, magnetic field plays a major role in influencing the hydrogen bubble evolution and conversion coating formation.

A commercial SVET/SIET system from Applicable Electronics Inc. (Forestdale, MA, USA) was used to investigate the concentration profile of the Mg^{2+} cations over the surface of AZ91D magnesium alloy. An Mg^{2+} selective microelectrode was used to measure the Mg^{2+} cation concentration, as described in Ref. [18]. The local concentration of Mg^{2+} was mapped sequentially 10 μm above the surface on a 30×30 grid. An optical microscope (model MeF3) was used to capture micrographs of the area scanned using the SIET, which enabled the correlation between the microstructure of the AZ91D magnesium alloy and the concentration profiles of the Mg^{2+} cation. X-ray phase-contrast radiography of hydrogen bubble evolution experiments was performed at the BL13W1 beam line (9 keV), Shanghai Synchrotron Radiation Facility, China. Real-time images were captured by X-ray CCD with a resolution of 2.25 μm/pixel.

The morphology of the conversion coating was characterized ex situ by scanning electron microscopy (model KYKY-EM3200). The surface topography of the conversion coating was measured ex situ by atomic force microscope (model CPII) in taping mode with a resolution of 256×256 pixels. We adopted Fourier analysis (power spectrum density) [19,20] to estimate the fractal dimension of the