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High corrosion-resistance nanocrystalline Ni coating on AZ91D magnesium alloy

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Abstract

Nanocrystalline (nc) Ni coating was direct-current electrodeposited on the AZ91D magnesium alloy substrate aimed to improve its corrosion resistance using a direct electroless plating of nickel as the protective layer. As comparison, two electroless Ni coatings on the magnesium alloy with different thickness were also presented in the paper. The surface morphologies of the coatings were studied by SEM and FESEM. The nc Ni coating had an average grain size of about 40 nm and an evident {200} preferred texture revealed by XRD. The hardness of the nc Ni coating was about 580 VHN, which was far higher than that (about 100 VHN) of the AZ91D magnesium alloy substrate. The electrochemical measurements showed that the nc Ni coating on the magnesium alloy had the lowest corrosion current density and most positive corrosion potential among the studied coatings on the magnesium alloy. Furthermore, the nc Ni coating on the AZ91D magnesium alloy exhibited very high corrosion resistance in the rapid corrosion test illustrated in the paper. The reasons for an increase in the corrosion resistance of the nc Ni coating on the magnesium alloy should be attributable to its fine grain structure and the low porosity in the coating.

Keywords: Nanocrystalline nickel; Magnesium alloy; Electroplating; Electroless nickel; Corrosion

1. Introduction

Magnesium is becoming increasingly significant as a lightweight metal structural material (with a density of 1.74 g/cm^3) in many industries—aircraft construction, space technology, optics, and automobile manufacturing, for example. However, magnesium is intrinsically highly reactive and its alloys usually have relatively poor corrosion resistance, which restricts the application of magnesium alloys in practical environments. So, it is often desirable to alter the surface properties of a magnesium or magnesium alloy workpiece in order to improve its corrosion and wear resistance, solderability, electrical conductivity or decorative appearance. This can be accomplished by coating the parts with a metal that has the desired properties necessary for the specific application [1].

Since magnesium is one of the most electrochemically active metals, any coatings on magnesium alloys should be as uniform, adhered and pore-free as possible. One of the most cost effective and simple techniques for introducing a metallic coating to a substrate is the plating techniques, including electroless plating and electroplating. Furthermore, magnesium is classified as a difficult substrate to plate metal due to its high reactivity. As for electroplating on the magnesium alloy, there are currently two processes used for plating on magnesium and magnesium alloys: direct electroless nickel plating and zinc immersion [2]. It can be noted that in many previous reports on the electroless plating on magnesium alloys [3–6], the nickel ions were provided by basic nickel carbonate in the plating bath. Different from the methods mentioned above, direct electroless nickel plating on the AZ91D magnesium alloy was

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recently undertaken by using a plating bath containing sulfate nickel [7].

In the recent years, there have been considerable interests in understanding the mechanical properties, the corrosion resistance and the wear resistance of nc metals produced by electrodeposition, for example [8–14]. According to them, nc materials exhibited many unusual mechanical and electrochemical properties compared with conventional polycrystalline or amorphous materials. So introducing a nc coating combined the high corrosion resistance with good wear resistance on magnesium alloy substrate would be very promising.

In the present paper, the electroless Ni plating from an acidic bath [7] was first deposited on AZ91D magnesium alloy as the protective layer for the further electroplating operation, and then a nc nickel coating was direct-current electroplated on the protective layer. The microstructures and the electrochemical properties of the coatings on the AZ91D magnesium alloy substrate were studied by SEM, FESEM, XRD and electrochemical measurement.

2. Experimental

The substrate material used was AZ91D die cast magnesium alloy with a size of $30 \times 40 \times 5$ mm. The alloy was mainly contained about 9.1% Al, 0.64% Zn, 0.17% Mn, 0.001% Fe and Mg balance. The samples were abraded with no.1500 SiC paper before the pretreatment processes. The technical flow chart of the electroplating on the AZ91D magnesium alloy is shown in Fig. 1. The samples were cleaned thoroughly with de-ionized water as quickly as possible between any two steps of the treatments. The direct electroless nickel plating with the thickness of about 10 μm on AZ91D magnesium alloy [7] was used as the protective layer for further plating on the magnesium alloy. The electroplating nc Ni coating on the magnesium alloy was direct-current electroplated from a bath containing nickel sulfate, nickel chloride, boric acid and saccharin at a pH of 5.0 and a temperature of 50 °C. During the electrodeposition process, the anode was used an electrolytic nickel plate. The operation of electroplating nc Ni coating was undertaken for about 30 min which would give the coating with the thickness of about 15 μm. A scanning electron microscope (SEM, JEOL JSM-5310, Japan) and a field emission scanning electron microscope (FESEM, JEOL JSM-6700F, Japan) were employed for the observations of the surface of the coatings and the cross-section morphology and an EDX attachment was used for qualitative elemental chemical analysis. Crystalline structure of the sample was studied by the X-ray diffractometer (XRD, Rigaku D/max, Japan) with a Cu target and a monochronmator at 50 kV and 300 mA with the scanning rate and step being 4°/min and 0.02°, respectively. The hardness of the magnesium alloy and the coatings were evaluated using a HXD-1000 micro-

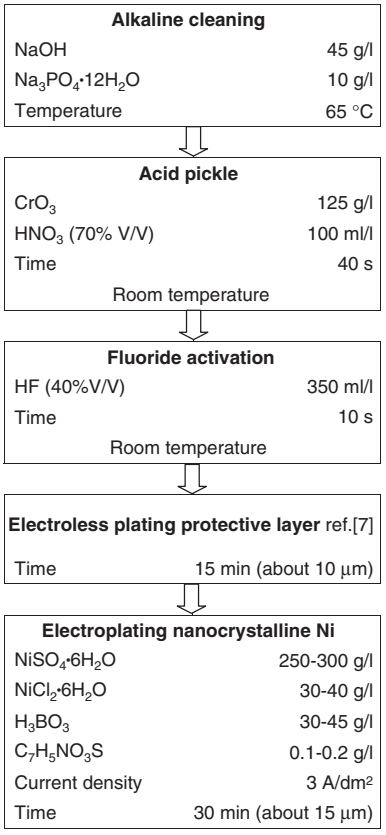

Fig. 1. The technical flow chart of the electroplating nc Ni on the AZ91D magnesium alloy.

hardness tester with Vickers indenter, at a load of 100 g and duration of 15 s.

Electrochemical measurements were performed on an Electrochemical Analyzer (CHI800, Shanghai, China), which was controlled by a computer and supported by software. Linear Sweep Voltammetry experiments were carried out in a 3 wt.% NaCl aqueous solution using a classic three-electrode cell with a platinum plate (Pt) as counter electrode and an Ag/AgCl electrode (+207 mV vs. SHE) as reference electrode. Before testing, the working electrode was cleaned in acetone agitated ultrasonically for 10 min. The exposed area for testing was obtained by doubly coating with epoxy resin (EP 651) leaving an uncovered area of approximately 1 cm^2. The reference and platinum electrodes were fixed near to the working electrode (about 0.5 mm), which could minimize the errors due to IR drop in the electrolytes. During the potentiodynamic sweep experiments, the samples were first immersed into 3 wt.% NaCl solution for about 20 min to stabilize the open-circuit potential. Potentiodynamic curves were recorded by sweeping the electrode potential from a value of about 300–400 mV lower to a value of 500–600 mV upper than the corrosion potential, respectively, at a sweeping rate of 5 mV/s. The $\log(i)$–E curves were measured and plotted after the above electrochemical measurements. The corrosion potential E_{corr} and corrosion