Microstructure and Corrosion Behavior of Electrodeposited Nanocrystalline Nickel Coating on AZ91 Mg Alloy

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1- Introduction
Mg and its alloys have superior physical and mechanical properties that make them excellent choices for application in the automotive and aerospace industries. Unfortunately low corrosion and wear resistance of Mg and its alloys limit their widespread use in many applications, particularly in atmospheres contributing to pitting corrosion. The most effective way to enhance the corrosion resistance of Mg alloys is to cover them with a barrier coating that can separate the base metal from the corrosive environment. Formation of oxide/hydroxide layers on the surface of Mg and its alloy in contact with air and water has a dreadful effect on the adhesion and uniformity of the coating. Many attempts have been made for nickel deposition on Mg and its alloys via different methods such as electroless and electroplating techniques [1-7]. Utilizing an appropriate pretreatment process is the most critical step in plating of Mg and its alloys. Developing a suitable under-coating is a key factor in adhesion, corrosion and other properties of the top layers. There are two main pretreatment processes for Mg plating including zinc immersion process [8-10] and electroless nickel plating [10-13].

The current work focuses on the development of an effective protective nickel layer on AZ91 Mg alloy and investigation of its corrosion resistance via EIS and polarization methods.

2- Experimental Work
As cast Mg alloy, AZ91, was used as a substrate. Specimens were immersed first in pickling bath, next activation bath, next zincating bath and then Cu electroplating bath. Nickel electroplating was conducted as the final step. After each step, specimens were rinsed using distilled water and immediately immersed in the following bath.

The surface morphology and elemental composition of the coating were characterized by the Scanning Electron Microscope (SEM) equipped with an X-ray energy dispersive spectrometer (EDS). Hardness of the coating, in the cross section, was determined using a Vickers micro-hardness tester.

Coating thickness was determined by observation of a cross section of the specimen by SEM. Philips X’Pert PRO type X-ray diffractometer (XRD) with copper target was used for microstructure determination. The grain size was estimated by the Scherrer equation [18]. The corrosion resistance of the specimens in 3.5 wt% NaCl solution with pH of 7 was assessed via polarization and EIS methods. For more comparison, the corrosion resistance of the AZ91 Mg substrate and pure nickel was measured.

3- Results and Discussion
Fig.1. shows the cross section image with line scan analysis of nickel electroplated AZ91 Mg alloy.

![Fig.1. SEM image of cross section and elemental line profile around coating-substrate interface of Ni electroplated AZ91 Mg alloy.](image)

It can be seen that the zincate process and the copper electrodeposition pretreatments have developed thin layers of Zn and Cu on the substrate that can enhance the adhesion of the nickel coating to the substrate [19]. Regarding the thickness of the coating, deposition rate of 30µm/h has been achieved from the current nickel bath.

The X-ray diffraction pattern of the coating is shown in Fig 2.

![Fig.2. XRD spectra of nickel electroplated AZ91 Mg alloy.](image)

Measurements carried out according to the Debye-Scherrer equation revealed that the coating has a nanocrystalline structure with the grain size of 95 nm. Micro hardness of the coating is about 204 HV50 while the micro hardness of the AZ91 Mg substrate is about 73 HV50. Figs 3, 4, and 5 show the Nyquist plot obtained for the AZ 91 Mg alloy, pure nickel, and electrodeposited nickel coating in 3.5 wt% NaCl solution at their respective OCPs, respectively.
The EIS patterns show obvious differences between corrosion behavior of the AZ 91 Mg alloy and the nickel coated specimen. It can be seen that the Nyquist curves appear to be similar with respect to their shape, noticing the charge controlled reaction; they differed considerably in their size.

An equivalent circuit model given in Fig. 6 has been utilized to simulate the metal/solution interface and to analyze the Nyquist plot of the specimens.

The potentiodynamic polarization curves of the specimens in 3.5 wt% NaCl solution are shown in Fig. 7.