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Short communication

The effect of PVD coatings on the corrosion behaviour of AZ91 magnesium alloy

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Abstract

In this study, multilayered AlN (AlN + AlN + AlN) and AlN + TiN were coated on AZ91 magnesium alloy using physical vapour deposition (PVD) technique of DC magnetron sputtering, and the influence of the coatings on the corrosion behaviour of the AZ91 alloy was examined. A PVD system for coating processes, a potentiostat for electrochemical corrosion tests, X-ray difractometer for compositional analysis of the coatings, and scanning electron microscopy for surface examinations were used. It was determined that PVD coatings deposited on AZ91 magnesium alloy increased the corrosion resistance of the alloy, and AlN + AlN + AlN coating increased the corrosion resistance much more than AlN + TiN coating. However, it was observed that, in the coating layers, small structural defects e.g., pores, pinholes, cracks that could arise from the coating process or substrate and get the ability of protection from corrosion worsened were present.

Keywords: AZ91; Magnesium alloy; Corrosion; PVD

1. Introduction

Because of their low density, high specific strength and stiffness, magnesium alloys have become candidate materials for many applications in microelectronics and in automobile and aerospace industries. The relative density of magnesium is 1.74 g/cm^3, which is 35% lower than that of aluminium, and typical magnesium alloys weigh ~35% lower than their aluminium counterparts at equal stiffness [1]. Magnesium and magnesium alloys are non-magnetic, have relatively high thermal and electrical conductivity, and good vibration and shock absorption ability [2].

In particular, their high strength to weight ratio makes magnesium alloys extremely attractive for applications requiring light weight, such as transport, aerospace, etc. A serious limitation for the potential use of several magnesium alloys is their susceptibility to corrosion and wear [3]. Corrosion resistance is especially poor when a magnesium alloy contains specific metallic impurities or when the magnesium alloy is exposed to aggressive electrolyte species such as chloride ions [4]. The corrosion rate of magnesium alloys increases usually with increasing in chloride ion concentration and decreasing in pH value in NaCl solutions [5]. If corrosion and wear resistance of magnesium alloys are increased, their usage will become widespread.

Surface modification by coatings has become an essential step to improve the surface properties such as wear, corrosion and oxidation. Various conventional techniques are utilized for depositing the desired material on to the substrate to achieve surface modification [6]. One of the most effective ways to prevent corrosion is to coat the base materials. Coatings can protect a substrate by providing a barrier between the metal and its environment and/or through the presence of corrosion

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inhibiting chemicals in them [7]. Many studies related to the surface modifications carried out on magnesium alloys and their protection ability against corrosion have been made in recent years.

In general way, films produced by physical vapour deposition (PVD) methods have many applications in the domains of hard coatings for their tribological properties, of thin layers in optics and microelectronics and as a protective coatings against corrosion. Nitride coatings, such as TiN, CrN, (Ti,AlN), AlN, (Ti,Cr)N..., have been the subject of intense studies [8]. Among them, aluminium nitride has been the subject of many studies because of its frequent use in electronics due to its performances as an electrical insulator and also due to its high thermal conductivity and relatively good resistance to oxidation [9].

AZ91 alloy has one of the best combinations of castability, and mechanical strength and ductility of all the magnesium-based alloys. This has made AZ91 a popular light metal alloy and the most preferred magnesium alloy. Therefore, the importance of AZ91 and other related magnesium alloys will continue to increase in the future [10].

The deposition of coatings via PVD technologies seems to be a possibility to overcome the drawbacks of magnesium alloys such as poor corrosion and wear resistance. However, the published knowledge is small compared with traditional methods of surface engineering for magnesium [11]. In addition, there is not sufficiently study about the effect of PVD coatings on the corrosion behaviour of magnesium alloys. Furthermore, to date, there has been no detailed study on the effect of the multi-layered PVD coatings on the corrosion behaviour of AZ91 alloy.

In this study, multilayered AlN (AlN + AlN + AlN) and AlN + TiN were coated on AZ91 magnesium alloy using PVD technique of DC magnetron sputtering, and the influence of the coatings on the corrosion behaviour of the AZ91 alloy was examined. A PVD system for coating processes, a potentiostat for electrochemical corrosion tests, X-ray difractometer (XRD) for compositional analysis of the coatings, and scanning electron microscopy (SEM) for surface examinations were used.

2. Experimental details

The chemical composition of AZ91 magnesium alloy used in this study was given in Table 1.

Table 1
The chemical composition of AZ91 magnesium alloy (wt%)

Al	Zn	Cu	Ni	Mn	Si
8.46	0.83	0.07	0.01	0.09	0.08

All coatings were carried out using a Teer Coatings Ltd., UDP 550 rig. Electrochemical polarization experiments were carried out using a potentiostat, Potentioscan Wenking POS 73. The electrochemical cell consists of the magnesium alloy as the working electrode, a saturated calomel reference electrode, and a platinum counter electrode.

Before the deposition process, the substrates were polished with emery paper until #1200 and Al_2O_3 paste (average size 1 μm), washed in distilled water and acetone, and dried in warm air. Afterwards, AlN + AlN + AlN and AlN + TiN films were coated on the AZ91 magnesium alloy substrate using DC magnetron sputtering method. An Al target for AlN + AlN + AlN coating, and an Al and a Ti target for AlN + TiN coating were used. The substrate to target distance was 90 mm. Prior to deposition, ion cleaning was carried out to avoid contamination and to improve adhesion [12]. Inert argon gas was used in ion cleaning processes. The films were deposited using the following process parameters: bias −60 V, pressure 0.4 Pa, and magnetron current 5 A. The coating period was 90 min for AlN + AlN + AlN coatings and 120 min (60 min AlN + 60 min TiN) for AlN + TiN coatings. For AlN + AlN + AlN coatings, the coating process of 30 min was repeated three times, and the coating process was stopped at the end of each 30 min. Al interlayer was deposited onto the substrates before AlN coating to obtain good adhesion [13] and corrosion resistance [14].

The potentiodynamic polarization scans were performed for uncoated and coated AZ91 alloy in a 0.6 M NaCl solution. The electrodes for this purpose were prepared by connecting a wire to one side of the sample that was covered with cold setting resin. One side of the specimen, whose area was 1 cm^2, was exposed to the solution. The polarization measurements were carried out in corrosion cell containing 500 ml solution at 28 °C. The specimens were immersed in the test solution, and a polarization scan was carried out towards more noble values at a rate of 1 mV/s, after allowing a steady state potential to develop.

3. Results and discussion

To eliminate the diffraction peaks scattering from the substrate in the XRD analysis of the coated AZ91 magnesium alloy, XRD analysis of uncoated alloy was also performed, and the XRD diagrams of the coated and uncoated alloy were shown together. Fig. 1 shows the XRD patterns of AlN + AlN + AlN and AlN + TiN coated AZ91 alloy. As shown in Fig. 1, for AlN + AlN + AlN coating, AlN showed peaks for the planes (1 0 1), (2 0 0) and (2 2 0). The relative intensity of the (1 0 1) peak was bigger than the others. AlN diffraction peaks observed in the XRD patterns