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Designing for the chemical conversion coating with high corrosion resistance and low electrical contact resistance on AZ91D magnesium alloy

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ABSTRACT

The designing idea for the chemical conversion coating with high corrosion resistance (CR) and low electrical contact resistance (ECR) on AZ91D Mg alloy was presented. The main characteristics of the conversion bath include acidic solution, strong oxidizing agent, proper pH value and cation concentration (determined by thermodynamic calculation). The desired performances are attributed to the unique microstructure of conversion coating, i.e., β phase protruded from the surface and covered by a thinner passive film about 30 nm, contributing to low ECR, meanwhile, a thicker coating of 200–300 nm without cracks was deposited on α-phase, providing a good corrosion resistance.

1. Introduction

Magnesium alloys have promising applications in aerospace, automotive, and 3C (Computer, Communication and Customer Electronic) industries due to its very interesting engineering properties such as its high specific rigidity, high thermal conductivity, electromagnetic compatibility and easy recycling. Unfortunately , there are some undesirable properties of magnesium and its alloys such as poor corrosion and wear resistance , poor creep resistance and high chemical reactivity, among which poor corrosion resistance is the main obstacle that hindered the widespread use of magnesium alloy especially for outdoor application. Coating technology is one of the most effective ways to protect the magnesium alloys from corrosion [1]. Thus, numbers of coating technologies for magnesium alloys including electrochemical plating [2–6], electroless plating [7–10], organic coating [11–13], chemical conversion coatings [14–32], plasma electrolytic oxidation (PEO) coating [33–45], sol-gel coating [46–49], ion implantation [50], laser treatment [51], vapor phase deposition [52], dipping and spraying processes have been developed over the past decades.

A new challenge for the coating technologies rises along with the extensive use of magnesium alloys in 3C electrical products, i.e. the coated surface is mandatory to satisfy the requirements of a lower electrical contact resistance (ECR) to ensure good electrical conductivity between integrated circuit broads and internal surface of magnesium alloy casing while maintaining high corrosion resistance. This electrical conductivity is essential to guarantee the continuous electrical contact, grounding and electromagnetic shielding of electronic devices [53–56]. For example, the internal surface of magnesium alloy Note-computer casing is typical required that its electrical resistance should be lower than 50 $m\Omega\, cm^{-2}$ and its corrosion lifetime in ASTM B117-03 standard salt fog experiment should be longer than 48 h, respectively.

Several methods such as metallic base coatings fabricated by electro or electroless plating and conversion coatings may be helpful in meeting the requirement of surface electrical conductivity. However, the metallic base coating is cathodic to the magnesium alloy substrate, which would lead to serious damage due to galvanic corrosion once aggressive media penetrated into the substrate through the pores of coating [2,3,11]. Over the past few decades, chromate conversion treatment is the main methods to satisfy such kind of requirements for avionics applications on aluminum alloys [53–55]. It is also considered to be viable on magnesium alloys [53]. However, due to the toxic and carcinogenic effects of hexavalent chromium compounds, there has been increasingly stringent legislation regarding their use and waste disposal [1,14,25]. It is on the agenda for the investigation of an

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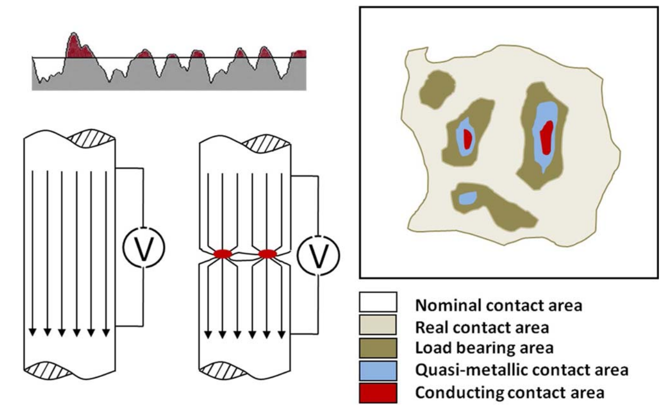

Fig. 1. Schematic diagram of the electrical contact resistance (ECR).

environment-friendly conversion coating that can satisfy the demand of 3C industry.

Recently, Lin [57] developed a permanganate conversion coating on AZ31 Mg alloy which claimed the electrical resistance is lower than 1 mΩ cm^{-2}. However, there is still a lack of knowledge regarding the ECR of non-chromate conversion coatings on magnesium alloys. According to general view, due to the nature of oxide or insoluble salts, the conversion coating itself should be distinguished as the non-conductive property. The corrosion resistance and electro conductivity of conversion coating seems conflictive (a high corrosion resistance should be poor in electrical conductivity). Thus, it is difficult to realize the conversion coating of magnesium alloy with the feature of high corrosion resistance and high electrical conductivity at the same time.

Such thinking set might originate in the misunderstanding of the difference between ECR and charge transfer resistance (R_t). In the view of physics, ECR means the extra increased resistance when a current flow went through an interface between two conductors (the detailed description of ECR will be present in background). As for R_t, it is a resistance for electrochemical reaction, which is defined as the resistance when the metal atoms are removed from their lattice sites to ionize as cations into electrolyte. By comparing the nature of ECR with that of R_t, it is indicative that they are not the same. The former is with the nature of physical process and associates with electric conduction, while, the latter is with the nature of electrochemical process and associates with corrosion. Thus, the corrosion resistance and ECR are totally different in physical nature. By lowering ECR and improving R_t respectively, a conversion coating with high corrosion resistance and high surface electrical conductivity may come true.

In order to figure out how to design a conversion coating with a low ECR on magnesium alloys, we should have a clear understanding of the concept of ECR. The ECR is the extra increased resistance offered to the flow of current during its passage through the interface between two conducting materials which are mating together (Fig. 1). The real solid surfaces are actually rough on the micro-scale which consists of peaks and troughs with different shape, height and distribution. When contact is made between two metals, only those surface asperities will actually contact and establish localized metal-to-metal contacts, and thus, the conducting path is defined as conducting spots [58]. Because of the existence of the conducting spots, there is a distortion and constriction of the electric current lines which reduces the volume of material used for electric conduction and thus increased electrical resistance. This increase in resistance is defined as the constriction resistance (R_c) of the interface. Generally, there may have areas with extremely thin film on the metallic contact area which can also make the current through by tunneling but increase the resistance of the contact spots, this additional resistance is defined as film resistance (R_f). Thus, ECR can be shown as following [59]:

$$ECR = R_c + R_f \quad (1)$$

Therefore, in the present study, we reported an idea of how to design a conversion coating with low ECR and high corrosion resistance. The conversion bath is designed as acidic solution containing strong oxidizing agent, and its pH value and the cation concentration for

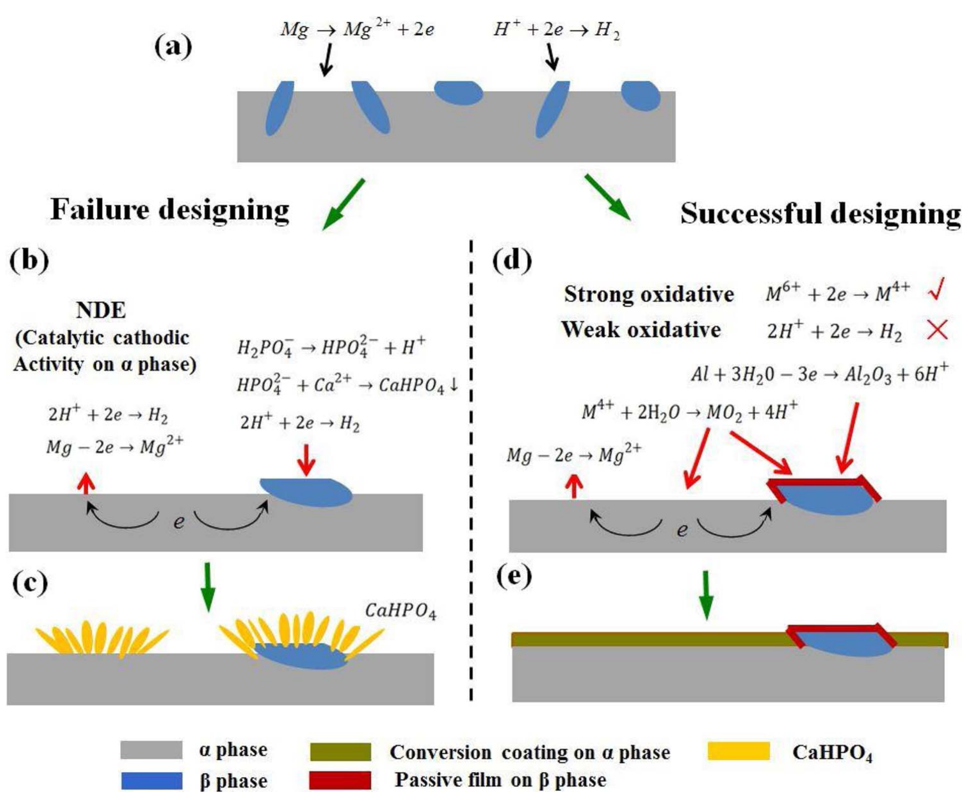

Fig. 2. Designing idea of the conversion coating with high corrosion resistance and low ECR.