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Synthesis of hybrid sol-gel coatings for corrosion protection of we54-ae magnesium alloy

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Abstract. The present work shows some preliminary results related to the synthesis, characterization and corrosion evaluation of different hybrid sol-gel coatings applied on the WE54-AE magnesium alloy attending to the two experimental variables, i.e. the precursors ratio and the aging time, which may affect the quality and the electrochemical properties of the coatings resultant. The experimental results confirmed that, under some specific experimental conditions, it was possible to obtain homogeneous and uniform, porous coatings with good corrosion resistance that also permit to accommodate corrosion inhibitors.

1. Introduction

Nowadays, it is well known that magnesium alloys are excellent candidates to reduce weight of the manufactured component without sacrificing its mechanic resistance. For this reason, these alloys are used in the transport industry, for the construction of train and aircraft fuselages, among others components for sport vehicles. One of the most important magnesium alloys is the WE54 alloy (Mg-Y-RE) that finds application at relatively high temperatures (up to 300ºC) for the construction of power systems, transmissions, and high performance cars due to their high strength and good creep resistance [1, 2].

Nevertheless, magnesium, as element, exhibit low chemical stability with a standard electrode potential of -2.37V, it being the most active metallic element utilized for structural applications [3-5]. This fact finally results in a severe decrease in corrosion resistance of their alloys in most of the frequent environments where magnesium might find potential application.

Among the protective coatings available for corrosion protection of magnesium alloys, particular interest has been focused on the sol-gel route, which is characterized by the formation of ceramic films with excellent corrosion resistance through successive reactions of hydrolysis and condensation of the corresponding precursors [6, 7]. With regard to other conventional methods, coatings prepared through this technique offer great advantages, i.e. great adhesion, low surface preparation and processing temperatures, use of relatively simple and inexpensive equipment, the possibility of application on complex shaped surfaces, etc.

In this regard, different precursors have been used to synthesize inorganic films such as SiO_2, TiO_2 or ZrO_2. However, due to their ceramic nature, these films cannot be growth without cracking for more than 1 micron. Recent studies are investigating the possibility of producing hybrid coatings, consisting

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in the addition of different organic precursors to the inorganic sol, which present organic groups such as epoxy (GPTMS) or amino (APTES), etc. that promotes crosslinking during of the sol-gel network and reduces both temperature and time during the curing process. As a consequence, the sol-gel films exhibit lower cracking susceptibility, high density and flexibility, and provide excellent mechanical properties and corrosion resistance [8, 9]. Further, hybrid sol-gel coatings are also interesting because of their porous structure since it permits to accommodate different kind of additives, e.g. corrosion inhibitors, such as rare earths elements, which provides an active self-curing effect [10-12].

Based on these statements, the aim of the work was to synthesize, characterize and evaluate the corrosion resistance of different hybrid sol-gel coatings applied on WE54-AE magnesium alloy.

2. Experimental

The material used in the present investigation was the WE54-AE magnesium alloy with nominal composition Nd: 1.5-2.0%; Y: 4.8-5.5%; RE: 1.0-2.0%; Zr: 0.4% y Mg: balance (%wt). Hybrid sols were prepared from a mixture of the inorganic precursor tetraethylorthosilicate (TEOS) and the organics precursors glycidoxypropyltriethoxysilane (GPTMS) and 3-aminopropyltriethoxysilane (APTES). Two experimental variables were fixed: the molar relation APTES:GPTMS (from 0.00 to 0.25:1) and the aging time (from 15 minutes to 24 hours). Later, sol-gel coatings were obtained by deposition of these sols following the dip-coating route. Finally, coatings were cured in two steps where temperature was increased progressively to prevent cracking: 60ºC (4 hours) and 120ºC (2 hours). Coatings were characterized using Scanning Electron Microscopy (SEM). Finally, corrosion resistance of the sol-gel coatings was evaluated by anodic potentiodynamic polarization test in aerated 0.1M NaCl solution after 30 min of stabilization [13].

3. Results and discussion

Figure 1 shows the electron micrographs of the hybrid sol-gel coatings performed on the WE54-AE magnesium alloy for different APTES: GPTMS molar ratios and aging times.

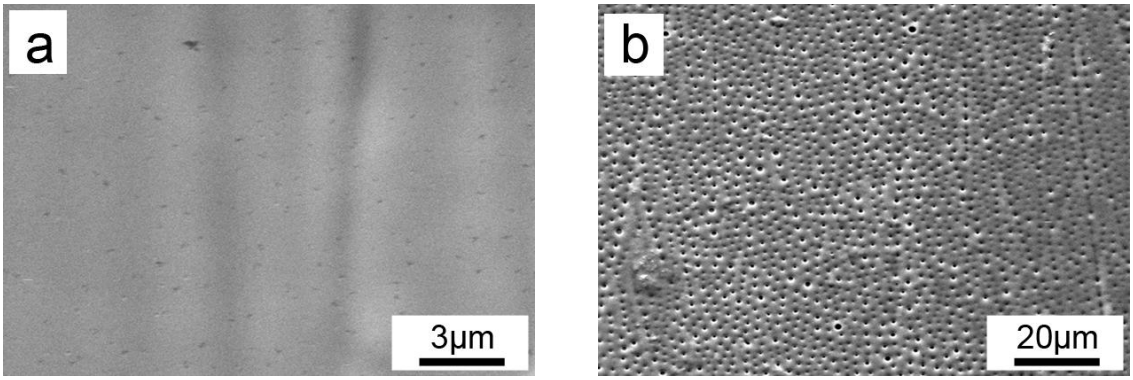


Figure 1. Electron micrographs of hybrid sol-gel coatings with APTES:GPTMS molar ratio and aging time of: (a) 0.00:1-24h and (b) 0.25:1-6h.

An increase of the aging time promoted the formation of continuous and uniform films, figure 1 (a). On the other hand, the addition of the APTES precursor accelerated the gelation process, which allowed obtaining coatings also uniform but with high grade of porosity, figure 1 (b). The latter was attributed to the presence of the NH_2 groups in the APTES precursor that shifts pH toward higher values and favoured the condensation process. This fact prevents the creation of an organized sol-gel structure and the continuous evaporation of the solvent (ethanol), which is finally trapped within the network. After dip-coating and during the curing process, the solvent rapidly evaporated resulting in the consequent porous structure.

Figure 2 shows anodic potentiodynamic polarization curves of the parent alloy and hybrid sol-gel coatings with different APTES: GPTMS molar ratios and aging times.

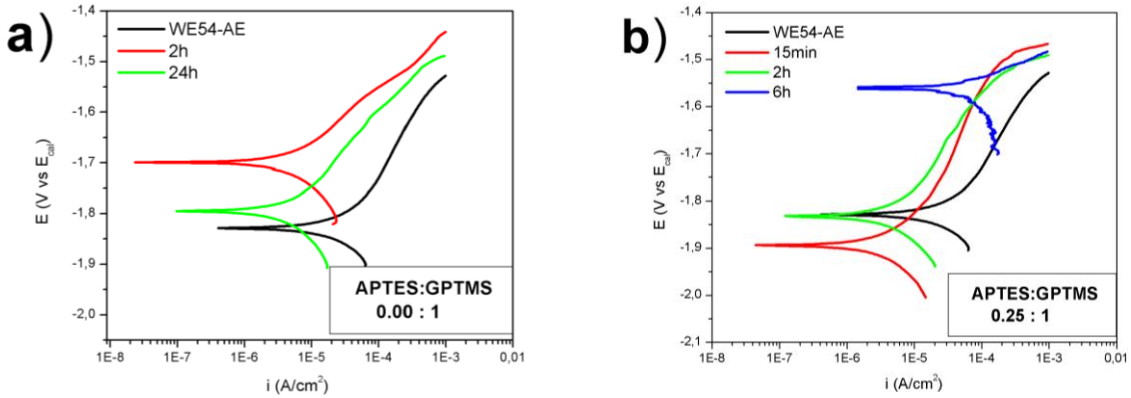


Figure 2. Anodic potentiodynamic polarization curves of the parent alloy and hybrid sol-gel coatings with APTES:GPTMS molar ratio of: (a) 0.00:1 and (b) 0.25:1 for different aging times.

In general, the hybrid sol-gel coatings enhanced the corrosion resistance of the parent alloy regardless of the addition of the APTES precursor, diminishing the corrosion current density by about one order of magnitude (See figure 2 (a)). Further, the addition of APTES, at short aging times, resulted in greater corrosion performance with also wider passivation range (Epit-Ecorr) (see figure 2 (b)). However, for longer aging times, the great porosity of the sol-gel network permits the easy diffusion of the corrosive species that promptly reaches the surface of the bulk alloy.

4. Conclusions

The sol-gel synthesis using mixture of inorganic-organic precursors allowed obtaining coatings with excellent surface characteristics of continuity and homogeneity. As a result, the corrosion performance of the WE54-AE magnesium alloy was significantly improved in terms of corrosion current density and passive features. The aging time and the APTES: GPTMS molar ratio affect the morphological features and the electrochemical properties of the coatings obtained: an increase of the aging time resulted in more continuous and homogenous coatings, while the addition of APTES promoted uniform coatings but with great porosity and lower corrosion resistance.

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References

[1] Mike D 2001 *Environmental Effects on Engineered Materials* (Nueva York: Marcel Dekker Inc.)
[2] Horst F, Barry L 2006 *Magnesium Technology* (Germany: Springer)
[3] Ling G, Atrens A 1999 *Adv. Eng. Mater.* **1** 11
[4] Kulekci M 2008 *J. Adv. Manufacturing Technol* **39** 851-65
[5] Tamar Y and Mandler D 2008 *Electrochim. Acta*. **53** 5118-27
[6] Liu D et al 2001 *Biomaterials* **22** 1721-30
[7] Wang D and Bierwagen G 2009 *Prog. Org. Coat.* **64** 327-38
[8] Guglielmi M 1997 *J. Sol-Gel Sci. Technol.* **8** 443-9
[9] Zheng S et al 2010 *J Sol Gel Technol.* **54** 174–87
[10] Yue Xu et al 2007 *J. Rare Earths.* **25** 193-6
[11] Schem M et al 2009 *Corros. Sci.* **51** 2304-15
[12] Gigandet M et al 2008 *Surf. Coat. Tech.* **202** 2052-8
[13] ASTM G3-89 1999 *Standard Practice for Conventions Applicable to Electrochemical Measurements in Corrosion Testing* (Estates Unites: American Society of Testing and Materials - ASTM)