Available online at www.sciencedirect.com
ScienceDirect
Trans. Nonferrous Met. Soc. China 23(2013) 1226−1236

Transactions of
Nonferrous Metals
Society of China

www.tnmsc.cn

Corrosion and electrochemical behavior of Mg−Y alloys in 3.5% NaCl solution

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Received 27 June 2011; accepted 14 December 2011

Abstract: The corrosion mechanism of Mg−Y alloys in 3.5% NaCl solution was investigated by electrochemical testing and SEM observation. The electrochemical results indicated that the corrosion potential of Mg−Y alloys in 3.5% NaCl solution increased with the increase of Y addition. The corrosion rate increased with the increase of Y addition because of the increase of $Mg_{24}Y_5$ intermetallic amounts. The corrosion gradually deteriorated with the increase of immersion time. The corrosion morphologies of the alloys were general corrosion for Mg−0.25Y and pitting corrosion for Mg−8Y and Mg−15Y, respectively. The main solid corrosion products were $Mg(OH)_2$ and $Mg_2(OH)_3Cl\cdot 4H_2O$.

Key words: Mg−Y alloy; polarization curves; pitting corrosion; corrosion products

1 Introduction

Magnesium is an attractive metal because of its low density of 1.74 g/cm^3, and relatively high abundance in earth crust (2.7%) and sea water (0.13%). Magnesium alloy can be an alternative to aluminum alloy in a wide range of fields, such as aerospace, electronic, automobile industries [1−4]. However, the corrosion performance of magnesium alloy is a major obstacle to its wider structural applications, despite their high specific stiffness, good machinability, high damping capacity, castability, weldability and recyclability.

Magnesium alloy is generally combined with alloying elements to improve its corrosion performance [5−7]. It is known that the addition of rare earth is an effective way to improve the corrosion resistance of magnesium alloys, which is mainly attributed to the formation of metastable RE-containing phases along the grain boundaries and such other reasons as the melt purity, decreasing activity of the alloy surface.

Yttrium is a useful alloying element for Mg alloys. Y-containing Mg alloys having good mechanical properties have been developed, such as WE54 [8], WE43 [9] and EW75 [10]. And these Y-containing Mg alloys also have good anti-corrosion properties. So yttrium is selected as alloying element [11,12]. Mg−Y alloys have three different intermetallic phases in different temperature ranges with increasing the content of Y, $Mg_{24}Y_5$, Mg_2Y and MgY [13]. Some characteristics of the mechanical properties of Y-containing Mg alloys have been studied [14,15], however, the corrosion properties of these alloys have received comparatively little attention [16−18]. MILLER et al [19] demonstrated that improved corrosion resistance of Mg−Y alloys was achieved when Y was confined to the solid solution. DAVENPORT et al [20] found that heat treatment and redistribution of the Y-rich regions in WE43 alloy could improve the corrosion resistance.

The aim of this work was to study the corrosion behaviour of three Mg−Y alloys in 3.5% NaCl solution. The effect of immersion time and Y concentration on corrosion resistance of the alloys was measured by electrochemical analysis and hydrogen evolution, scanning electron microscopy (SEM), energy dispersive X-ray spectrometry (EDS) and low-angle X-ray

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Foundation item: Project (2011BAE22B01) supported by the National Key Technology R&D Program of China
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DOI: 10.1016/S1003-6326(13)62587-X

diffractometry (XRD).

2 Experimental

2.1 Materials

Mg−Y alloys were prepared according to the procedure designed by LI et al [21]. They were prepared in a crucible furnace under the protection of CO_2+SF_6 gases and cast in a water cooled metallic model. Pure magnesium and pure yttrium were used as raw materials.

The actual compositions of the Mg−Y alloys were determined by inductively coupled plasma-atomic emission spectrometry (ICP-AES) and the results are presented in Table 1.

Table 1 Actual composition of Mg−Y alloys

Alloy	Chemical composition/%	
	Y	Mg
Mg−0.25Y	0.24	Bal.
Mg−8Y	7.46	Bal.
Mg−15Y	13.78	Bal.

For metallographic characterization, the samples were prepared by ingot casting process. The specimens were encapsulated by epoxy resin with a surface of 10 mm×10 mm exposed to the solution. The specimens were wet ground through successive grades of silicon carbide abrasive papers from P120 to P1500 followed by diamond finishing to 2.5 μm in water, degreased with acetone, washed with deionized water, rinsed with isopropyl alcohol in an ultrasonic bath and dried in cool flowing air before tests. All tests were performed in duplicate to guarantee the reliability of the results. The etching reagent of 5 mL HNO_3+95 mL ethanol was used to reveal the constituents and general microstructure of Mg−Y alloys.

2.2 Immersion tests and products analysis

The immersion tests were conducted in the 3.5% (mass fraction) NaCl solution, which was prepared with AR grade NaCl and distilled water, at room temperature for 2 h and 24 h.

The corrosion rate was evaluated by measuring the evolved hydrogen during immersion in the 3.5% NaCl solution. The specimen was horizontally immersed in 1500 mL solution and the hydrogen evolved during the experiment was collected in a burette above the sample [22]. The corrosion rate, P (mm/a), was related to the evolved hydrogen rate, V (mL/(cm^2·d)) by [23]

$$P=2.279V \quad (1)$$

After the immersion test, the specimens were then quickly washed with distilled water and dried in warm flowing air. The samples were immersed in a 400 mL aqueous solution of 10% CrO_3+1% $AgNO_3$ in boiling condition for 5−8 min to remove the corrosion products. The corrosion morphologies of the samples were observed by JSM-6510A scanning electron microscope (SEM) equipped with an energy dispersive X-ray spectrometer (EDS). In order to get the corrosion products, the samples were immersed in the solution for 72 h. The corrosion products were investigated by grazing incidence X-ray diffraction using Cu $K_{\alpha 1}$ (λ=0.154056 nm) radiation at a constant incidence angle of 1° to the specimen surface. The crystalline phases were identified using the JCPDS database cards.

2.3 Electrochemical measurements

The parameters of electrochemical measurements were obtained in 5% NaCl solution using the Potentioatat/Galvanostat Model 273A and HF Frequency Response Analyzer SI1255. A classical three-electrode cell was used with platinum as counter electrode, saturated calomel electrode SCE (0.242 V vs SHE) as reference electrode, and the sample as working electrode. The samples were mounted using epoxy resin and only left an exposed area of 1 cm^2. The measurements began from the cathodic side at a constant voltage scan rate of 0.5 mV/s after the initial retard of 300 s. The perturbing signal of AC amplitude was 5 mV and the frequency ranged from 100 Hz to 5 mHz.

3 Results

3.1 Microstructural characterization

The microstructure of as-cast Mg−Y alloys consisted of primary α-Mg, yttrium-rich net-segregation $Mg_{24}Y_5$ phases, as illustrated in Fig. 1. In Mg−Y alloys, yttrium was in solid solution and precipitated in the form of second phases along grain boundaries. The yttrium gathered around grain boundaries and formed the network structures, and some casting defects were also distributed in the microstructure. There were some $Mg_{24}Y_5$ eutectic structures on the grain boundaries as shown in Fig. 2. $Mg_{24}Y_5$ particles looked like bright pearls enchased on the grain boundaries (Fig. 1(b)), and the amount of the intermetallic or eutectic $Mg_{24}Y_5$ phases increased with the increase of yttrium addition.

3.2 Hydrogen evolution

Figure 3 presents the hydrogen evolution with immersion time for Mg−Y alloys in 3.5% NaCl solution. In the initial stage, the hydrogen evolution was little. With the increase of immersion time, the corrosion rates