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The effect of Ca and rare earth elements on the microstructure, mechanical properties and corrosion behavior of AZ91D

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Abstract

The microstructure, mechanical properties and corrosion behavior of AZ91 with addition of Ca and rare earth elements (REs) were investigated using tensile tests, X-ray diffraction, SEM, EDX, immersion tests and electrochemical polarization experiments. The addition of 1%Ca led to the formation of reticular Al_2Ca phase, which improved the corrosion resistance of AZ91D alloys. The reticular Al_2Ca phase had a detrimental influence on the mechanical properties of AZ91 alloys; however, the addition of REs improved the ultimate tensile strength of the AZ91 alloy, but the corrosion resistance increased slightly compared with the addition of Ca. With the addition of 1%Ca and 1%REs to AZ91, the ultimate tensile strength increased by 15.9% and the corrosion rate decreased to 0.086 mg cm^{-2} day^{-1} due to the formation of the reticular Al_2Ca phase, which acted as an effective barrier against corrosion.

Keywords: Magnesium; Ca; Rare earth elements; Corrosion; Microstructure; Electrochemical polarization

1. Introduction

The need for weight reduction, particularly in portable microelectronics, telecommunication, aerospace and automobile sectors has stimulated engineers to be more creative in their choice of materials. Magnesium and its alloys, with one quarter of the density of steel and only two-thirds that of aluminium, and a strength to weight ratio that far exceeds either, fulfils the role admirably, as an 'ultra light' alloy. Although a wide variety of applications can be envisaged for Mg alloys, the use at present is limited mainly due to inferior corrosion properties [1–5].

New magnesium alloys have been developed in recent years to meet the need for high temperature creep resistance in the automotive industry. Magnesium alloys with Al and Zn have found wide spread application in the automobile sector. Corrosion performance is therefore quite important as it concerns the operating life of magnesium alloy components in a vehicle. The addition of rare earth elements and Ca is an effective way to improve the mechanical properties of magnesium alloys at elevated temperatures [6,7]. Some have reported [8–11] on the corrosion behavior of the commercial alloy AZ91, which is widely used in low-temperature applications. Nevertheless, there are a few researches concerning the effect of RE additions on corrosion performance [12–14] and few researches concerning the effect of Ca additions on the corrosion performance of magnesium alloys. The aim of the present work was to study the interaction of Ca and RE elements on the microstructure, mechanical properties and corrosion resistance of magnesium alloys.

2. Experimental method

In this work, six new AZ91D–*x*Ca alloys, four new AZ91D–*x*RE alloys and four new AZ91D–1%RE–*x*Ca alloys were studied. The chemical composition of the proposed alloys is given in Table 1. Tensile tests were conducted on a Zwick T1-FR020TN.A50 electronic universal material testing machine. The Rigaku Dmax-rc X-ray diffractometer and PHILIPS SEM 515 were employed to analyze phase composition and corrosion morphology respectively.

For corrosion immersion tests, the specimens were polished successively on finer grades of emery papers up to 800 grit. Cleaning of the specimens at the end of the experiment was

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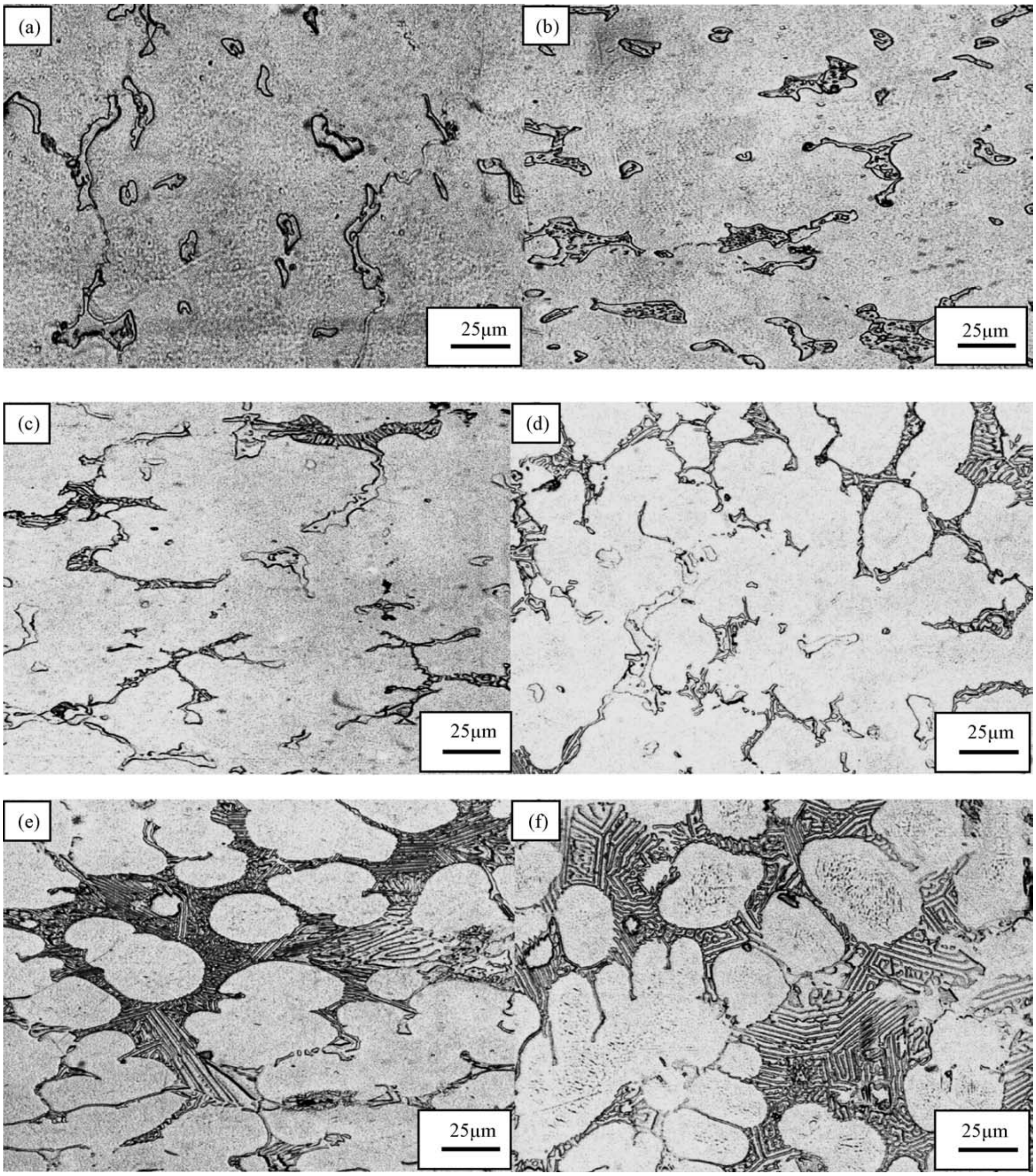

Fig. 1. Optical microstructure of as-cast AZC alloys (a) AZC03, (b) AZC05, (c) AZC1, (d) AZC2, (e) AZC3, (f) AZC4.

done by dipping in a solution of 15%CrO_3 + 1%$AgNO_3$ in 400 ml water at boiling condition. The extent of corrosion was given in weight loss per surface area and time (mg cm^{-2} day^{-1}, or MCD). The size of immersion test specimens was Ø35 mm × 4 mm.

Electrochemical polarization tests were carried out in a corrosion cell containing 200 ml of 5 wt.% NaCl using a standard three electrode configuration: saturated calomel as a reference with a stainless steel electrode as counter and the sample as the working electrode. A ZF-10 measurement system was used. Specimens were immersed in the test solution and a polarization scan was carried out at a rate of 1 mVs^{-1}, after allowing a steady state potential to develop.

3. Experimental results

3.1. Microstructure

3.1.1. Effect of Ca on microstructure

Fig. 1 shows the influence of Ca on the microstructure of the AZ91D magnesium alloy. The microstructure of AZ91D alloy was composed of α(Mg) matrix and $Mg_{17}Al_{12}$ phase [15,16], which precipitated along grain boundaries. When Ca addition was not more than 0.5%, the microstructure of AZ91D which is shown in Fig. 1(a and b), was still composed of α and $Mg_{17}Al_{12}$ phase. It was evident that the Ca addition refined the dendrite cell size and the size of the $Mg_{17}Al_{12}$ phase on