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Effects of Cu on microstructure, mechanical properties and damping capacity of high damping Mg–1%Mn based alloy

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ABSTRACT

In this paper, a high damping Mg–1%Mn based alloy with good corrosion resistance and adequate strength was prepared by studying the properties of Mg–Mn alloys. The effects of Cu addition on microstructure, mechanical properties and damping capacity of Mg–1%Mn alloy were investigated. The results show that Cu addition remarkably reduces the grain size of Mg–1%Mn alloy and a new binary phase, Mg_2Cu, can be identified, which segregates at grain boundaries in the form of divorced eutectic and worsens the tensile properties. Using a low strain amplitude, the damping capacities of Mg–Cu–Mn alloys show minor variation with increasing Cu content, while with a high strain amplitude, the internal friction decreases with the smaller grain size and increasing amount of precipitates. In addition, the temperature dependent damping behavior of the Mg–Cu–Mn alloys was also discussed.

1. Introduction

In order to meet the increasing need for special active control devices in aerospace, automotive and electronics industries, the development and applications of high damping alloys are considered to be an important area. Among various metallic materials, pure magnesium exhibits the best damping properties, the lowest specific gravity, excellent machining abilities and good recycling potential [1,2]. Nevertheless, the poor mechanical properties of pure Mg have restricted its practical application to a large extent. Therefore, a great deal of research work had focused on the damping magnesium alloys with improved strength, such as Mg–0.6%Zr [3,4] and Mg–3%Ni [5,6] alloys. Moreover, as-cast Mg–(0.5–7.0)Cu–(0.17–4.0)Mn (mass fraction, %) alloys possessing good castability, preferable damping capacity and adequate tensile strength have been reported by Nishiyama [7]. In spite of this, specific analysis of the damping and strengthening mechanisms of Mg–Cu–Mn alloys was limited in his study. In addition, Zhang et al. [8] investigated the effects of Cu and Mn on the mechanical properties and damping capacity of Mg–Cu–Mn alloy. However, the obvious decrease in the ultimate tensile strength when Cu and Mn addition was 3% and 1%, respectively, was not explained in this research.

The purpose of the present investigation is to provide a better understanding of the as-cast high damping Mg–Cu–Mn alloy. In this paper their microstructure, mechanical properties and damping capacity are systematically studied and compared with traditional high damping Mg–0.6%Zr and Mg–3%Ni alloys.

2. Experimental

As-cast pure Mg, Mg–Mn, Mg–Cu–Mn, Mg–3%Ni and Mg–0.6%Zr alloys were prepared with high-purity pure Mg (99.99%), Mg–5%Mn, Mg–30%Cu, Mg–80%Ni and Mg–30%Zr master alloys. The Mg billets were melted in a resistance furnace under a mixed CO_2 and SF_6 protective atmosphere. At a temperature of 770 °C, the corresponding master alloys were added. The alloy melts were stirred and held for 10 min at 750 °C, the melt was subsequently poured into a steel-mold which was preheated to 250 °C and then cooled in air. The nominal compositions of the studied alloys are shown in Table 1.

The microstructure of the as-cast alloys was examined with an MDS optical microscope. Further micro-compositional analysis of certain phases was carried out on a Quanta400 scanning electron microscope (SEM) equipped with Oxford X-ray energy dispersive spectrometer (EDS). The phase constitutions were identified by an X'pert PRO X-ray diffraction (XRD) using Cu Kα radiation under a scanning rate of 4°/min. A JEM-2100F high resolution transmission electron microscope (HRTEM) was used to observe lattice arrangements and dislocation configurations. The mechanical properties of the studied alloys were tested on a RGM-X050 tensile testing machine with a crosshead speed of 4 mm/min at room temperature. The gauge length of the sample was 20 mm and the cross-sectional diameter, 8 mm. Corrosion tests were performed in 3.5 wt% NaCl

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Table 1
Nominal compositions of studied alloys (mass fraction, %).

Alloy no.	Composition
1	Pure Mg
2	Mg–0.5%Mn
3	Mg–1.0%Mn
4	Mg–2.0%Mn
5	Mg–3.0%Ni
6	Mg–0.6%Zr
7	Mg–1%Mn–0.5%Cu
8	Mg–1%Mn–1.5%Cu
9	Mg–1%Mn–3.0%Cu

aqueous solution at ambient temperature with a CS310 electrochemical workstation with a potential scan rate of 5 mV/s.

Strain dependent damping tests were conducted at various maximum strains from 1×10^{-5} to 1×10^{-3} at room temperature with the frequency held at 1 Hz using a Q800 dynamic mechanical analyzer (DMA) in single cantilever deformation mode. Rectangular bending beam specimens with dimensions of 40 mm × 5 mm × 1 mm for the damping measurements were processed using electric spark cutting. The damping capacity was determined by $Q^{-1} = \tan\Phi$, where Φ is the lag angle between the applied strain and the response stress. For the measurements of temperature dependent damping capacity, the tests were carried out on an EXSTAR6100 dynamic mechanical spectrometer (DMS) with a tension deformation module. The dimensions of the specimen were 40 mm × 6 mm × 0.5 mm. The strain amplitude used was 1×10^{-5} and the vibration frequency used was 1 Hz. Samples were tested at temperatures between 25 °C and 450 °C with a heating rate of 2 °C/min.

3. Results and discussion

3.1. Properties of Mg–x%Mn alloys

Fig. 1 shows the damping capacities of pure Mg, Mg–*x*%Mn, Mg–3%Ni and Mg–0.6%Zr alloys as a function of the strain amplitude. As can be seen in Fig. 1, all the damping curves can be divided into two obvious parts: the first part in the lower strain range, the strain amplitude has little influence on the damping values. However, in the second part, after the strain amplitude reaches a certain value, the damping capacities increase rapidly with rising strain amplitude. The turning point of curve is corresponding to the critical strain. In all of the studied alloys, pure Mg shows the smallest critical strain of 2.5×10^{-5} and highest damping parameter of 0.015 with low strain amplitude. While with a high strain amplitude, Mg–*x*%Mn alloys exhibit extraordinarily high internal friction. For example, when the strain amplitude is higher than 1×10^{-3}, the damping values of Mg–0.5%Mn and Mg–1%Mn alloys even exceed that of pure Mg and Mg–0.6%Zr alloys, and are also higher than the Mg–3%Ni alloy.

The results of tensile tests of pure Mg, Mg–*x*%Mn, Mg–3%Ni and Mg–0.6%Zr alloys are shown in Fig. 2. It is observed that the addition of Mn to the Mg improves tensile strength. By adding 1.0%Mn, the ultimate strength of the alloy increase by 23.1% compared to the pure Mg. When Mn content is increased further to 2%, the strength could reach 126.9 MPa, a value comparable to that of high damping Mg–3%Ni and Mg–0.6%Zr based alloys. In this work, the Mg–1%Mn alloy is selected for further study because this alloy presents an attractive balance between the damping capacity and mechanical properties compared to the Mg–2%Mn alloy.

The potentiodynamic polarization curves obtained in 3.5 wt% NaCl aqueous solution for pure Mg, Mg–1%Mn, Mg–0.6%Zr and Mg–3%Ni alloys at ambient temperature are shown in Fig. 3. The corrosion potentials (E_{corr}), the corrosion currents density (I_{corr}) and corrosion rate of various samples calculated from potentiodynamic polarization curves by Tafel analysis are summarized in

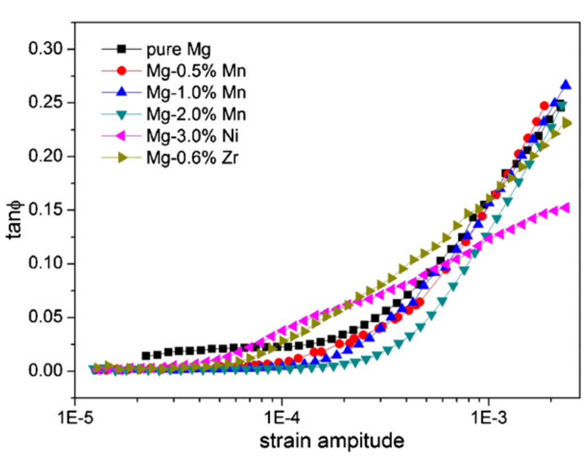

Fig. 1. Strain amplitude dependent damping capacity of pure Mg, Mg–*x*%Mn, Mg–3%Ni and Mg–0.6%Zr alloy, respectively.

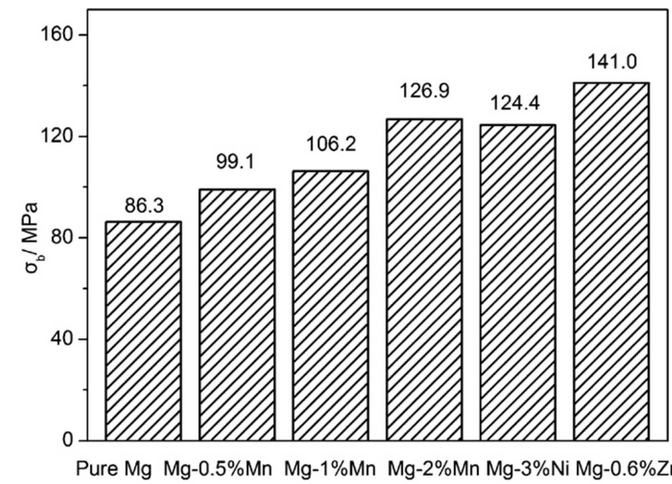

Fig. 2. The ultimate tensile strength of pure Mg, Mg–*x*%Mn, Mg–3%Ni and Mg–0.6%Zr alloy, respectively.

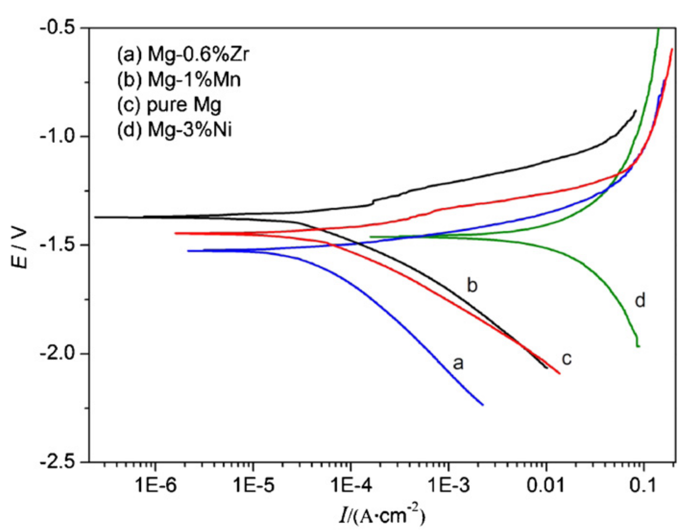

Fig. 3. Potentiodynamic polarization curves for pure Mg, Mg–1%Mn, Mg–3%Ni and Mg–0.6%Zr alloy, respectively.