



Ultrahigh strength MgZnCa eutectic alloy/Fe particle composites with excellent plasticity



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ABSTRACT

The influence of Fe particle addition on MgZnCa eutectic-composition as-cast alloy was investigated. No difference was observed in the other main crystal phases, except for the Fe particles. Compared with the as-cast Mg₆₉Zn₂₇Ca₄ ternary system, the alloy with Fe added exhibited higher strength and plasticity. The fracture stress of Mg₆₉Zn₂₇Ca₄ with 4 vol% Fe reached nearly 700 MPa with 12% plasticity. The porous Fe particles increased the strength and toughness of the alloy.

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1. Introduction

Ultrafine eutectic composites with microscale dendrites are novel materials used to improve the room-temperature plasticity of high-strength alloys [1–4]. Alloys with a eutectic composition show excellent casting performance and machinability [5]. Eutectic composites are usually converted into bulk metallic glass (BMG) composites to improve its elastic modulus and strength [6–8]. Among all eutectic composition alloys, magnesium alloys, as the lightest structural materials, have attracted the attention of researchers. The combination of Mg-based eutectic composites and BMGs is highly attractive because of their ultrahigh specific strength and good corrosion resistance [9,10].

However, these alloys usually have poor plasticity because plastic deformation is heterogeneous [11]. Most Mg-based eutectic composites catastrophically fail without a distinct plastic strain at room temperature, thereby limiting their potential applications. Various methods have been introduced to improve the plasticity of these materials, including adding ductile phase or particles, such as Fe or Mo, and introducing prefabricated defects [12–14]. However, most of these methods are performed in BMGs. Studies on the enhanced toughness in Mg-based eutectic composite alloys are seldom reported. BMGs are not widely used in engineering applications because of their high cost and difficulty in preparation. Recent studies have focused on MgZnCa eutectic composition

because of the low density of this alloy. However, the majority of research focused on MgZnCa BMGs [15,16]; studies on eutectic composites are lacking. Methods to improve the mechanical properties of the Mg-matrix eutectic composition alloy have yet to be developed.

In this study, Fe particles were added into the MgZnCa eutectic composition as-cast alloy. E2 eutectic composition (Mg₆₉Zn₂₇Ca₄ alloy) was selected based on the MgZnCa system schematic ternary diagram. The structure and mechanical properties of were investigated.

2. Experimental

The raw materials used were as follows: industrially pure Mg (99.9 wt%), Zn (99.9 wt%), and Mg–30Ca alloy (30 wt% Ca). A master alloy with the composition of Mg₆₉Zn₂₇Ca₄ was prepared by induction melting raw materials with induction furnace under the production of high-purity Ar atmosphere. During melting, high-purity, irregularly shaped Fe particles with the granularity of 300 were added into the matrix alloy under Ar atmosphere. Mechanical stirring was performed to enhance the homogeneous mixing of the particles with the melt. Fe particles (4 vol%) were added to the Mg₆₉Zn₂₇Ca₄ alloy. Then, the melting alloy was injection into a quartz glass tube with 3 mm diameter and cooled in air. Finally, a cylindrical rod with 3 mm and 50 mm length was produced.

The structure was characterized by X-ray diffraction (XRD, Rigaku D/MAX-2500PC) using Cu K α radiation. The morphology

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and elemental composition were determined by Vega II LMU SEM equipped with an EDS. The mechanical properties were tested by compressive experiments. Compressive specimens with 1.5 mm diameter and 3 mm length were used for the experiments on a SANS CMT5105 testing machine at a strain rate of 10^{-4} s^{-1} at room temperature. At least three samples were tested for each composition.

3. Results and discussions

Fig. 1a shows the XRD patterns of the as-cast $\text{Mg}_{69}\text{Zn}_{27}\text{Ca}_4$ (alloy I) and that with 4 vol% Fe particles (alloy II). Many crystal peaks appeared in both alloys. The main sharp diffraction peaks were identified to be mixtures of hexagonal α -Mg, hexagonal MgZn_2 , and tetragonal $\text{Ca}_2\text{Mg}_5\text{Zn}_{13}$ phases. Except for the three high-intensity crystalline peaks, no difference in the main peaks of the two alloys was observed. This result indicates that no obvious changes occurred in the crystalline peaks. The high-intensity crystalline peaks were indexed as Fe phases. Therefore, no inter-metallic compound can be formed between the Fe and $\text{Mg}_{69}\text{Zn}_{27}\text{Ca}_4$ matrix.

The SEM backscattering electron micrographs of the MgZnCa and MgZnCa/Fe composites are shown in Fig. 1b and c respectively. Alloy I is composed of the primary α -Mg, the skeleton-like dendritic phase, and some bulk phases. However, the skeleton-like dendritic phase declined and a volume fraction of bulk phase was found as Fe content increased. Dendritic arm spacing and grain size in alloy I were obviously larger than those in alloy II. EDS showed that only Mg and Zn were found in the fine dendrite, indicating that this dendrite corresponds to the MgZn phase. The bulk phase in alloy I mainly consisted of the $\text{Ca}_2\text{Mg}_5\text{Zn}_{13}$ phase. In

alloy II, the dendrite was mainly composed of Mg and Zn. This result indicates that the dendrite also corresponds to the MgZn phase. The bulk phases in alloy II were rich in Fe, suggesting that the bulk phases in alloy II are Fe particles.

Fig. 2 shows the surface scanning results of the area around the bulk phases and the element distribution of Mg, Zn, Ca, and Fe for alloy II. Only Fe was present in the bulk phases. This finding is similar to the EDS results, which means that the bulk phases are all Fe particles. The dendritic phase mainly consisted of Mg, Zn, and a few Ca. No defects or cracks were found between the Fe particles and the matrix.

Fig. 3 shows the comparison of the mechanical properties of the alloys. The addition of Fe particles improved both the strength and plasticity of the alloy. The compressive strength and plasticity of the alloy with 4% Fe particles increased from 340 MPa to 700 MPa and from 0 to nearly 12%, respectively. The low mechanical properties of the MgZnCa alloy can be attributed to the mechanical failure exhibited before reaching the elastic limit. This failure does not occur when Fe particles are added. The Fe-added alloy had a TYS of 520 MPa. This finding confirms that the combination of Fe particles and MgZnCa matrix maintains the high strength of the Fe particles and the good plasticity of the ductile particles.

Fig. 4 shows the fracture morphologies of the alloys. Alloy I showed a large amount of cracks (Fig. 4a). The surface of the sample was very rough because some of the alloy fragmented during the compressive experiment, indicating that the alloy is brittle. Cleavage-like features and some fragments were observed on the fracture surface of the dendrite/matrix composites (Fig. 4b). These results reveal the brittle nature of the alloy.

MgZnCa with 4 vol% Fe was not thoroughly fractured. The heading state of the alloy is shown in Fig. 4c. The main crack

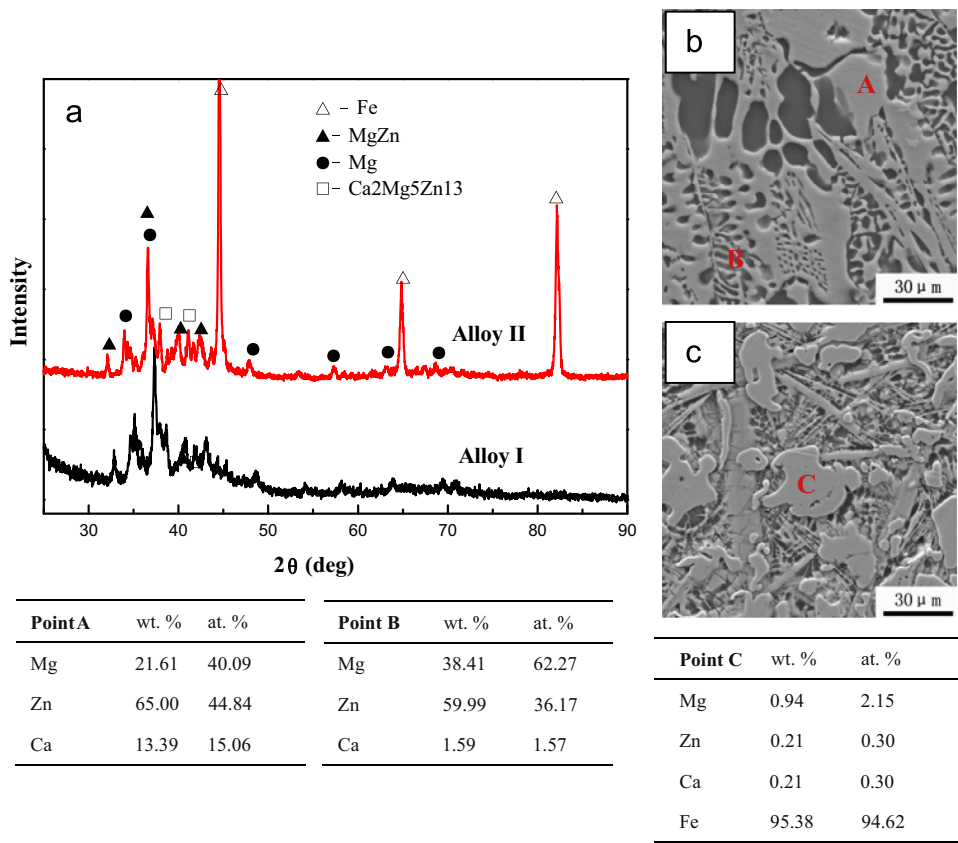


Fig. 1. Microstructures of the MgZnCa and MgZnCa/Fe alloys: (a) XRD patterns of the two alloys; (b) and (c) SEM image of the MgZnCa and MgZnCa/Fe alloys.

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