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The development of a new grain refiner for magnesium alloys using the edge-to-edge model

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Abstract

A potential new grain refiner, ZnO, for magnesium alloys was identified using the edge-to-edge matching crystallographic model. The effects of various levels of ZnO additions on the grain size of pure magnesium and a Mg–Zn alloy were investigated. Experimental results show that an addition of 3 wt.% ZnO powder to pure magnesium reduces the grain size from 1100 to 410 μm. The grain size of a Mg–Zn alloy can also be decreased from 420 to 310 μm when 1 wt.% ZnO powder is added.

Keywords: Edge-to-edge matching; Grain refinement; Magnesium alloys; ZnO

1. Introduction

Magnesium alloys are usually classified into two broad groups, aluminium-free and aluminium-containing alloys. Zirconium (Zr) has been recognized as the most effective grain refiner for Mg alloys without Al. The preparation of a master alloy containing Zr particles and the grain refinement process and mechanism have been investigated in detail [1–4]. However, the latter is largely ineffective in terms of grain refinement of Mg–Al alloys due to the strong binding reaction between Al and Zr. To date, the available grain refinement processes for Al-containing Mg alloys include a melt superheating technique, the Elfinal processes and carbon inoculation [5,6]. However, these processes suffer from a number of disadvantages, such as lower grain refinement efficiency, complex processes, that limit their practical industrial application. Hence, development of more effective and reliable grain refiners for this type of alloy is technologically important and necessary.

Partly due to the lack of a consistently accepted framework for understanding the grain refinement mechanism, progress in this field over the past decades has been very slow. Most attempts to find new grain refiners have been based on the time-consuming trial and error route [7–9]. Recently, Zhang et al. have successfully explained the grain refining efficiency and mechanisms of a number of currently available grain refiners for both aluminium and magnesium alloys from a crystallographic perspective using the edge-to-edge matching model [10–13]. This research indicated that this model could be used to identify new grain refiners, in particular for the Mg alloy families.

In the last two years, two key tools have been developed: (1) a crystallographic database containing almost all binary and ternary compounds that can possibly form in aluminium and magnesium alloys; (2) a computer program to carry out the edge-to-edge matching model calculations between any two compounds of known crystallography. By combining the database and the computer program, a number of potential grain refiners for Mg alloys have been predicted. One of the predicted candidates is ZnO which has a simple HCP structure (ZnS type) and belongs to the *P*63*mc* space group. Its lattice parameters are $a = 0.3265$ nm and $c = 0.5219$ nm, which are very close to those of pure magnesium, $a = 0.320936$ nm and $c = 0.521123$ nm [14]. Hence, from a crystallographic point view, ZnO should act as an efficient grain refiner for magnesium alloys.

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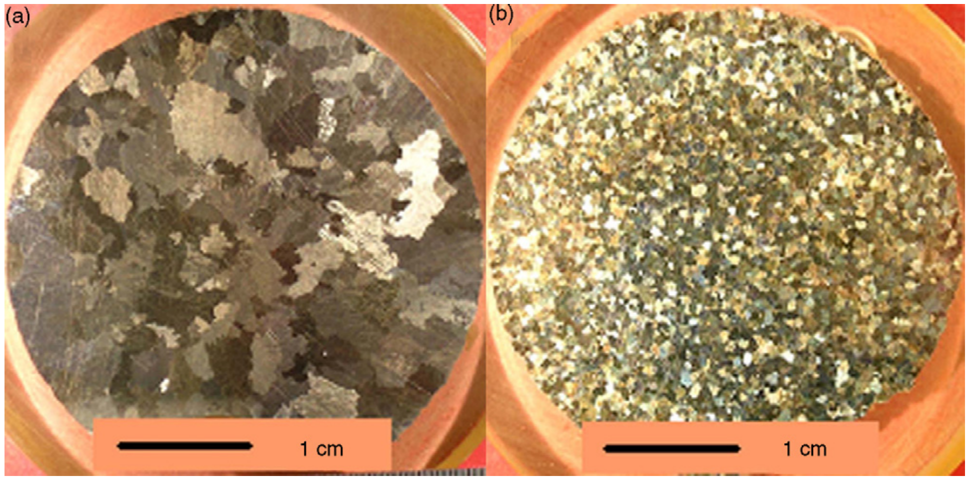

Fig. 1. Macrostructures of (a) pure magnesium and (b) pure magnesium containing an addition of 3 wt.% ZnO powder.

In the present work, the effects of ZnO additions on the grain sizes of as-cast pure magnesium and Mg–Zn alloys have been investigated.

2. Experimental

Pure Mg (99.94%) or Mg–3 wt.% Zn alloy melts was prepared in boron nitride coated mild steel crucibles in an electrical resistance furnace. A cover gas of composition 1% SF_6–50% CO_2–49% dry air was used to protect the melts from oxidation. The melt temperature was $720 \pm 5\,^{\circ}C$. Additions of ZnO at various levels were made to melt by mixing the powder (with particle size < 1 μm) with pure magnesium chips and then compacted into small discs.

The samples were collected using a boron nitride coated mild steel tapered cone cup from the centre of the melt and cooled in air until solidification was complete. The dimensions of the tapered cup were Ø 55 mm (top) × Ø 35 mm (base) × 60 mm (length) with wall thickness of 1.5 mm for pure magnesium and Ø 34 mm (top) × Ø 21 mm (base) × 37 mm (length) with wall thickness of 2 mm for Mg–Zn alloy. The cups were preheated by holding them immediately above the melt for 20 s prior to submergence.

Each of the samples were sectioned at ∼13 mm from the base. These sections were ground, polished and then etched. The grain structure of each sample was examined using optical microscopy and the mean grain size at the centre of each sample was measured using the linear intercept method. The microstructures were further examined using a scanning electron microscope with energy dispersive X-ray (EDX) analysis capabilities.

3. Results

The macrostructures of pure Mg and of pure Mg with an addition of 3 wt.% ZnO powder are shown in Fig. 1a and b, respectively. Due to the relatively slow cooling rate of the cup samples, the structure of the pure Mg sample consists of coarse equiaxed grains instead of columnar grains. It can be clearly

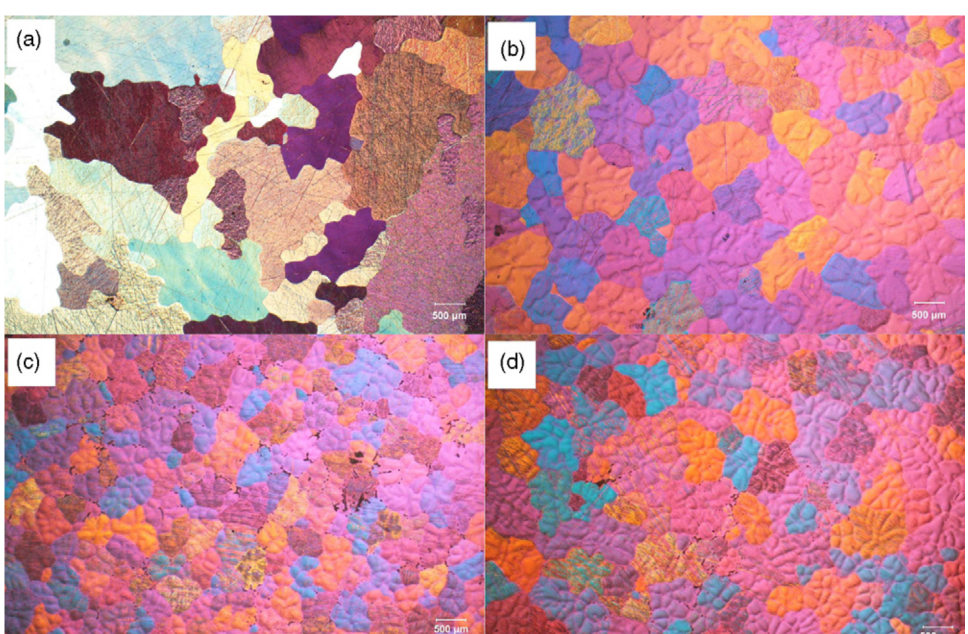

Fig. 2. Typical microstructures of pure magnesium with different addition levels of ZnO powder: (a) no addition, (b) 2 wt.%, (c) 3 wt.%, and (d) 4 wt.%.