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Short Communication

The effect of alternative low frequency electromagnetic field on the solidification microstructure and mechanical properties of ZK60 alloys

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A R T I C L E   I N F O

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A B S T R A C T

The effect of alternative low frequency electromagnetic field (ALFEF) on ZK60 alloys during solidification process was investigated. The grains were refined and more uniformly distributed, second phase precipitates at grain boundaries were reduced and had finer eutectic structure, provided that the ALFEF was applied to ZK60 alloys during the solidification process. Grain refinement of ZK60 alloys is due to the electromagnetic force under the ALFEF. Stirring helps crystallization melt and dendritic crystal break. In comparison with no electromagnetic condition, the tensile strength and elongation of ZK60 alloys under the ALFEF increase by 9.5% and 72.5%, respectively. Based on these results, this paper has further investigated the microstructure and mechanical properties of alloys under extrusion, which showed that finer and more uniform microstructure and improved mechanical properties were obtained.

1. Introduction

Magnesium alloys have extensive applied foreground for replacing steel and other high density materials due to their low density, high specific strength, good performance on damping capacity and electromagnetic shielding in aerospace, automobile industry, electronic communication, and civil home appliances fields [1–4]. However, Mg has poor strength and plastic deformation because of the hexagonal close-packed crystallographic structure which limits its further application [5,6]. Therefore, how to improve the comprehensive performance of magnesium alloys has become more and more important. Controlling the solidification microstructures and refining grains are a kind of effective method to do this [7]. ZK60 alloy is one of the most typical high-strength wrought Mg alloys. Considerable attention was concentrated lately on the study of the influence of heat treatment on the mechanical properties of ZK60 alloys subjected to plastic deformation, including extrusion, rolling and forging. Chen's research showed that annealing treatment at 375 °C for 10^3 s can be considered to be the optimum annealing treatment of ZK60 alloys, and under this condition the tensile strength, yield strength and elongation are 388 MPa, 301 MPa and 22.9%, respectively [8]. Wang et al. [9] studied the hot working behavior of ZK60 magnesium alloy by squeeze casting in the temperature range of 523–723 K and strain rate range of 0.001–10 s^{-1} by establishing processing maps. The power dissipation map reveals that a domain of dynamic recrystallization (DRX) occurred in the temperature range of 573–648 K and strain rate range of 0.001–0.01 s^{-1}, which are the optimum hot working parameters. Low temperature superplastic (SP) behavior (mechanical and deformation mechanisms) of two commercial Mg-based alloys (AZ31 and ZK60) was characterized by Bussiba et al. [10]. Although low temperature was applied, the ZK60 exhibited superplastic-like behavior and the maximum peak of elongation (220%) was detected at 1×10^{-5} s^{-1} with m equal to 0.2. A ZK60 magnesium alloy with the addition of *Y* was thixoforged by Zhao et al. [11]. The semi-solid thermal transformation (SSTT) route and the recrystallisation and partial melting (RAP) route were used to obtain the semi-solid feedstocks for thixoforging. Results show that a fine spheroidal microstructure can be obtained by the RAP route.

In recent years, the electromagnetic field has a rapid development in which electromagnetic stirring was applied to investigate the process of alloy solidification and control the solidified microstructures and material performance. A lot of research has been done on electromagnetic stirring [12–14], but seldom research done on the solidified microstructures and mechanical properties of ZK60 alloys under ALFEF. The effect of the ALFEF on the solidification and mechanical properties of the ZK60 alloys was analyzed on this paper.

2. Experimental details

The commercial ZK60 alloy was selected as the raw material on this study. Its chemical composition (mass fraction, %) is as follows: Zn 6.52%, Zr 0.56% and Mg Balance. The experiment was conducted by a self-developed ALFEF device which is shown in Fig. 1. The device uses nine self-developed iron core coils which

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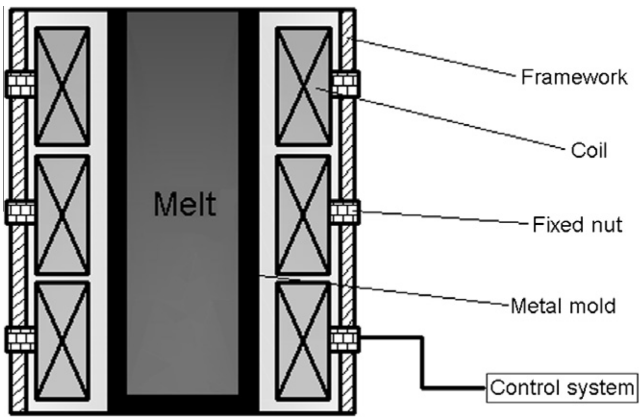

Fig. 1. Sketch of the experimental apparatus.

fit together on framework and the whole system is composed of three layers with three coils for each layer. Two wiring heads of each coil are drawn out in order to generate current and stimulate magnetic field. And the melt will solidify under the electromagnetic field. The electromagnetic stirring principle is shown in Fig. 2.

The ZK60 alloys was first remelted at 760 °C for 30 min in an electrical resistance furnace using a graphite crucible. The melt was poured into a preheated (to 350 °C) stainless steel mold with a diameter of 45 mm, height of 200 mm and a wall-thickness of 10 mm. The ALFEF was continuously imposed on the melt until it completely solidified, and then the sample in the mold was taken out immediately by water quenching. The ALFEF parameters: voltage 70 V, current 5.66 A. For the sake of contrastive analysis, the

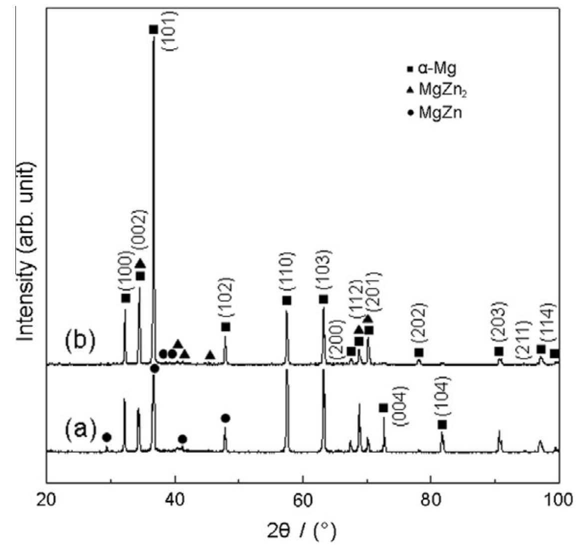

Fig. 4. XRD pattern of as-cast ZK60 alloys. (a) Without magnetic field. (b) With ALFEF.

same experiment was carried out without ALFEF. Extrusion experiment was carried out at die temperature 350 °C and ingot temperature 300 °C to prepare round bars with a diameter of 8 mm. The corresponding extrusion ratio was 1:25 and extrusion rate was 0.15 mm/s.

The metallographic specimens of both casting and extrusion alloys were prepared and the microstructures were observed by optical microscope. Before the test, all samples were polished by

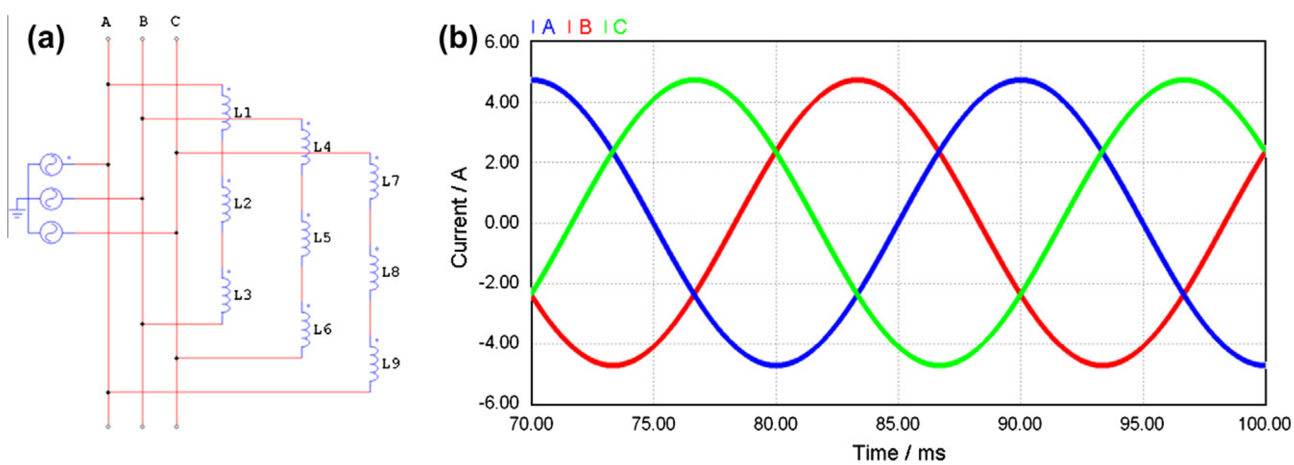

Fig. 2. Electromagnetic stirring principle (a) schematic of ALFEF and (b) current simulation waveform.

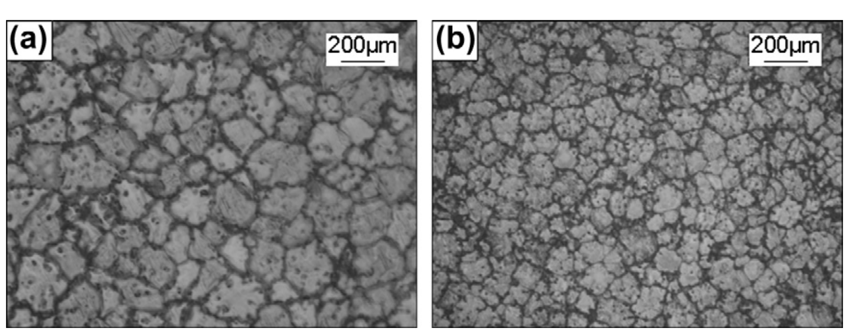

Fig. 3. Microstructures of the ZK60 alloys. (a) Without magnetic field. (b) With ALFEF.