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Mechanical and damping properties of thermal treated Mg–Zn–Y–Zr alloys reinforced with quasicrystal phase

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ABSTRACT

The effects of annealing, T4 and T6 heat treatment on microstructure, mechanical properties and damping capacities of a quasicrystal-reinforced Mg–Zn–Y–Zr alloy (the ZWK3 alloy) were investigated in this study. The structural results show that the $Mg_{0.97}Zn_{0.03}$ phase could transform to Mg_7Zn_3 phase during annealing and only primary phase and the I-Mg_3YZn_6 quasicrystal phase exist in the T4 treated ZWK3 alloy. Further aging in T6 treatment precipitates a large amount of nanoscaled $MgZn_2$ phase. The thermal treatment could improve the tensile strength of the ZWK3 alloy greatly, while a large reduction in elongation and high strain amplitude damping are obtained compared with that of the as-cast alloy. In spite of this, the damping values of three heat treated ZWK3 alloys all exceed 0.01, representing our studied alloys still belong to high damping magnesium alloys. Decrease of mobility of dislocations, resulting from tanglement and pinning, is responsible for damping decline. We also find that twins only observed in the T6 treated ZWK3 alloy could produce new damping sources besides dislocation.

1. Introduction

Magnesium alloys have a lot of unique advantages such as high specific strength, electromagnetic shielding capacity, good casting and cutting machinability and recyclability, especially the excellent damping capacities [1]. The Mg–Zn–Y alloys reinforced with I-Mg_3YZn_6 quasicrystal phase, with both high strength and good damping capacity, have become a research hotspot in damping magnesium alloy area [2]. The quasicrystal particles, with high hardness and good thermal stability, are especially suited to be strengthening phases in ductile matrix to further improve the mechanical properties [3]. The formation mechanism of icosahedral quasicrystal phase (I-phase) in Mg–Zn–Y alloys under traditional solidification conditions has been studied systematically [4–8], and the strengthening effect of the I-phase and the relationship between the I-phase and the magnesium matrix are discussed in depth as well [3,9,10]. The results show that the interface between the I-phase and matrix is stable during thermal–mechanical processes without the formation of defects such as cavities. Besides, no coarsening occurred on I-phase at elevated temperatures due to their good high temperature stability [11]. The effect of I-phase on damping capacities of Mg–Zn–Y alloys has also been mentioned in some literatures [12,13]. The stable, clean and high bonding strength I-phase/matrix interface without generating additional dislocations is believed to be the key reason that the damping capacity has been maintained after the strength improved obviously [14].

Similarly to other Mg–Zn–Re alloys, the mechanical properties of the Mg–Zn–Y alloys could be further improved through heat treatment such as solution and aging. The precipitation of the I-phase could occur on interfaces in Mg–Zn–Y alloys during hot extrude processes, and the increase amount of I-phase is beneficial to improve mechanical properties [15]. Most studies on heat treatment of Mg–Zn–Y alloys focus on the synthesized impact of high temperature and deformation during thermal–mechanical processes [16,17], while little concern the influence of high temperature on phase composition, mechanical properties and especially damping capacities of Mg–Zn–Y alloys during static heat treatment.

Thus, in this paper, the effect of high temperature annealing, solution (T4) and aging (T6) on microstructure, mechanical properties and damping capacities of a quasicrystal-reinforced Mg–Zn–Y–Zr alloy will be investigated in detail. It is hoped our study could provide a better understanding to damping behavior of magnesium alloys.

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2. Experimental

The Mg–Zn–Y–Zr based alloy we use is Mg–3.0 wt%Zn–0.6 wt% Y–0.6 wt%Zr alloy, ZWK3, which has been reported to exhibit both high strength and good damping capacity at room temperature [14]. This ZWK3 alloy was fabricated through adding Zn, Y and Zr into pure magnesium. The Mg–Y and Mg–Zr master alloy was added successively when the pure Mg and Zn ingot was melted and heated to 750 °C. The melt should be stirred for at least 5 min and then heated to 780 °C and kept for at least 10 min. The melt was then cast at 700 °C into a permanent mold which was preheated to 250 °C with a pair of electric heating boards. The annealing (350 °C × 8 h), T4 (425 °C × 24 h) and T6 (425 °C × 24 h + 200 °C × 24 h) heat treatment were carried out on the as-cast ingots, respectively.

The microstructure test was carried out on an environment scanning electronic microscope (ESEM, Quanta 200), and the phase composition was examined on an X-ray diffraction (XRD, X'pert PRO). The mode for XRD examination is continuous scan, with a scan speed of 10°/min within a range of 10°–80°. An Image-Pro Plus software (Media Cybernetics, Inc.) was used to measure and count the grain sizes of the as-cast and heat treated ZWK3 alloys. Further micro-analysis such as precipitates, dislocation and twin investigation was carried out on a transmission electron microscope (TEM, JEM 2100). The TEM foils were prepared by jet electron polishing followed by ion beam thinning on a Gatan precision ion polishing. The tensile tests were performed on a Zwick Z100 universal testing machine with a test speed of 1 mm/min. The width, thickness and length of parallel part of specimen for tensile test are 5, 2, and 16 mm, respectively. Four specimens were tested for each parameter of heat treatment. A dynamic mechanical analysis (TA-DMA Q800) was used to measure the strain amplitude dependent damping of the ZWK3 alloys at room temperature. The specimens for DMA test were processed to a size of $50 \times 5 \times 1$ mm^3 through wire-electrode cutting. A single cantilever vibration mode was used and the vibration frequency was held at 1 Hz. The strain amplitude varied with the scope ranging from 1×10^{-5} to 2×10^{-3}.

3. Results and discussion

3.1. Microstructure

The SEM results of the heat treated ZWK3 alloys are shown in Fig. 1. From the images it can be seen that the microstructure of as-cast ZWK3 alloy consists of massive grains, inter-grain eutectics

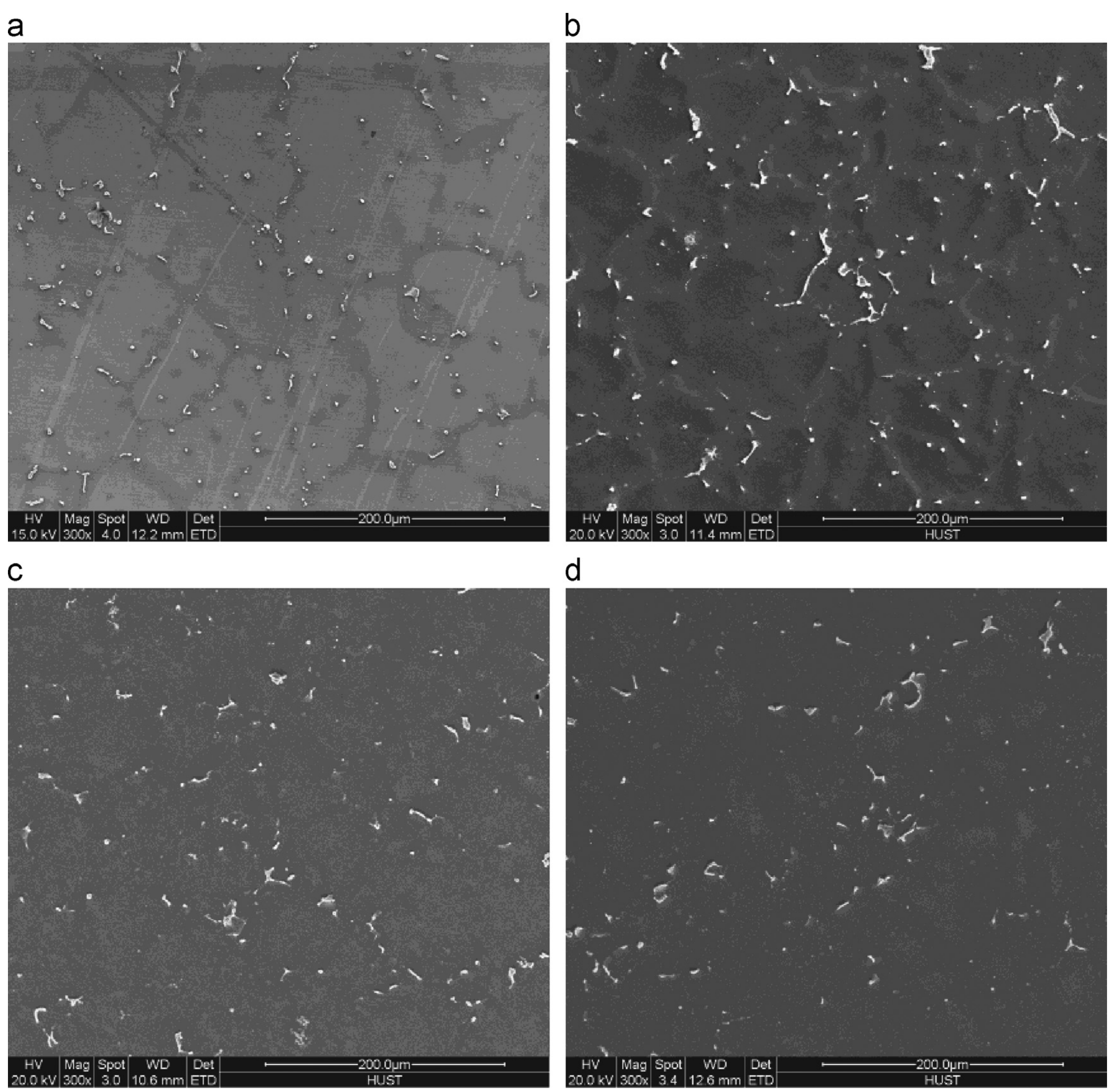

Fig. 1. Scanning electron microscopy images of as-cast and heat treated ZWK3 alloys. (a) As-cast; (b) annealed: 350 °C × 8 h; (c) T4: 425 °C × 8 h; (d) T6: 425 °C × 8 h + 200 °C × 24 h.