Materials and Design 84 (2015) 48–52

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/jmad

Electrical and thermal conductivity in Mg–5Sn Alloy at different aging status

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ARTICLE INFO

Article history:
Received 22 April 2015
Received in revised form 14 June 2015
Accepted 15 June 2015
Available online 26 June 2015

Keywords:
Mg–Sn alloy
Aging treatment
Microstructure
Electrical conductivity
Thermal conductivity

ABSTRACT

The electrical conductivity, thermal conductivity and its relationship with the microstructure in Mg–5Sn alloy aged at 513 K for different aging times were investigated systematically in this paper. The results show that the electrical conductivity and thermal conductivity obviously increase with the increasing aging time, and its values increase from $10.25 \times 10^6\ S \cdot m^{-1}$ to $13.7 \times 10^6\ S \cdot m^{-1}$, $87.5\ W \cdot m^{-1} \cdot K^{-1}$ to $122\ W \cdot m^{-1} \cdot K^{-1}$ after aging treatment for 120 h, respectively. Meanwhile, it is found that there exist quite different relationships between unit cell volume and thermal conductivity in early and later aging stages.

1. Introduction

Magnesium alloys are the lightest weight commercially available structural materials, which have high specific strength and stiffness, good thermal and electrical conductivity [1,2]. Therefore, magnesium alloys are attractive candidates for heat dissipation materials in LED etc., compared with aluminum alloys. The Mg–Sn alloys, known as a typical precipitation hardening system [3], have great potential applications in heat dissipation materials at elevated temperatures (<423 K) due to the Mg_2Sn phase, which has a high melting temperature of 1043 K [4–6]. For Mg–Sn alloys, most researchers have given more attention to the improvement of aging hardening on the performance of the alloys [7–10]. Thermal conductivity is an important thermophysical property for heat dissipation materials. The higher the thermal conductivity, the more effective the cooling is [11]. Some researchers have studied the thermal conductivity of as-cast and as-extruded Mg-based alloys [11–18]. A. Rudajevova et al. have found that thermal conductivity is sensitive to the microstructure of as-cast Mg alloys [11–14]. M.Y. Zheng et al. recently have studied the thermal conductivity of as-cast and as-extruded Mg–Al/Zn alloys [15,16] and found that the anisotropy of thermal conductivity resulted from microstructure anisotropy because of the texture formed during extrusion [17]. The phase transformation and the different effects of Zn and Al on the thermal/electrical conductivity have also been studied by F.S. Pan et al. [18]. It is well known that the conductivity of the aging-treated materials is better than that of as-cast and solution-treated materials. This is mainly due to the precipitation of the dissolved elements out of the solutions. However, few papers pay attention to the thermal properties of aged Mg-based alloys, especially the relationship between the precipitates and thermal conductivity. The paper mainly focuses on the effects of the aging status on the electrical conductivity and thermal conductivity of aged Mg–Sn alloys, and tries to discuss the relationship between the precipitates and thermal conductivity for different aging status.

2. Experimental

The Mg–5 wt.% Sn alloys were prepared from high purity Mg (99.95%) and pure Sn (99.98%), melted in a low-carbon steel crucible under the protection of $N_2 + SF_6$ mixed gas. The melt was stirred to ensure homogeneity and held at 993 K for about 30 min, and then cast in steel molds preheated up to 533 K. The specimens for electrical and thermal conductivity measurement were cut into slices with 14.0 mm × 14.0 mm × 3.0 mm and discs with a diameter of 12.7 mm and a thickness of 2.88 mm, respectively. The samples were solution treated for 28 h at 733 K and quenched into water at room temperature. Subsequently, the specimens were isothermally aged at 513 K for different times.

The samples for microstructural characterization were polished and etched with a solution of 4 vol.% nital. The microstructures and phase characterizations were investigated by scanning electron

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http://dx.doi.org/10.1016/j.matdes.2015.06.110
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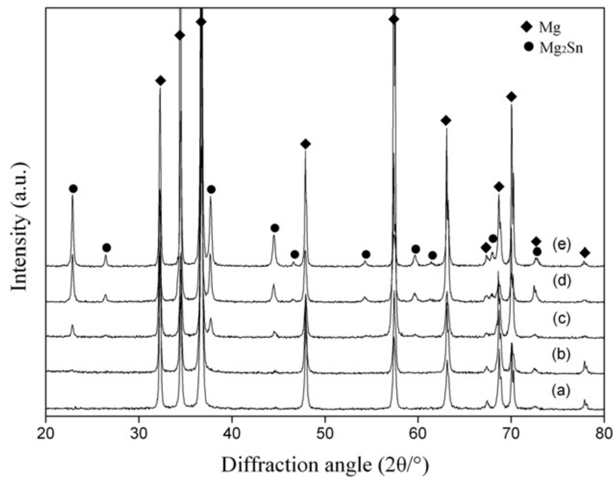

Fig. 1. XRD patterns of Mg–5Sn alloys with different aging times at 513 K, (a) 0 h, (b) 6 h, (c) 20 h, (d) 64 h, and (e) 120 h.

Table 1
The lattice parameters of α-Mg phase of the aged Mg–5Sn alloys.

Aging time, h	Lattice parameters, nm		Volume, nm^3	Mg_2Sn, vol. %
	a	c		
0	0.3211	0.5209	7.752×10^{-3}	–
6	0.3210	0.5208	7.746×10^{-3}	–
20	0.3208	0.5207	7.735×10^{-3}	0.3
64	0.3208	0.5205	7.732×10^{-3}	1.5
120	0.3207	0.5203	7.724×10^{-3}	2.9

microscopy (SEM, JEOL, JSM-6490LV) and X-ray diffraction (XRD, DanDongFangYuan, DX-2600) with Cu Kα radiation, respectively. The precipitate microstructures after aging treatment were observed using transmission electron microscopy (TEM, JEM-2010UHR) equipped with Energy Dispersive X-ray (EDS, Noran Vantage DS) operating at 200 kV. The foils were prepared by ion-milling using the Precision Ion Polishing System (GATAN691). The age hardening responses were measured by the Vickers hardness tester (HVS-1000) under a load of 25 g.

The electrical conductivity of the aging samples was measured by an eddy-current device (FIRST FD-101) at room temperature. The probe (probe diameter, Φ: 8 mm) of the device was put in the smooth surface of the samples, and led to eddy current by forming the loop. According to the International Annealed Copper Standard (% IACS) with a ± 1% accuracy, the range of electrical conductivity measurements was from 6.9% IACS (4.0 $MS \cdot m^{-1}$) to 110% IACS (64 $MS \cdot m^{-1}$). The thermal diffusivity was measured at room temperature (298 K) with a NETZSCH model LFA447 Flash Analyzer. The surface of the specimen discs was blackened by carbon-coating in order to improve the absorption of the light pulse. The density of the samples at room temperature was determined by the Archimedes method. The specific heat capacity of the alloy was calculated using the Neumann–Kopp rule [19,20]. Thus, the thermal conductivity (λ) of the samples was calculated by the following equation [21]:

$$\lambda = \alpha \rho c \tag{1}$$

where λ is the thermal conductivity, α is the thermal diffusivity, ρ is the density and c is the specific heat capacity.

3. Results and discussion

3.1. The microstructure of aged Mg–5Sn alloy

The XRD patterns of Mg–5Sn alloys with different aging times at 513 K are shown in Fig. 1. According to the indexed results, there are only α-Mg (PDF: No. 35-0821) and Mg_2Sn (PDF: No. 07-0274) phases in aged Mg–5Sn alloy, and the diffraction peak intensities of the

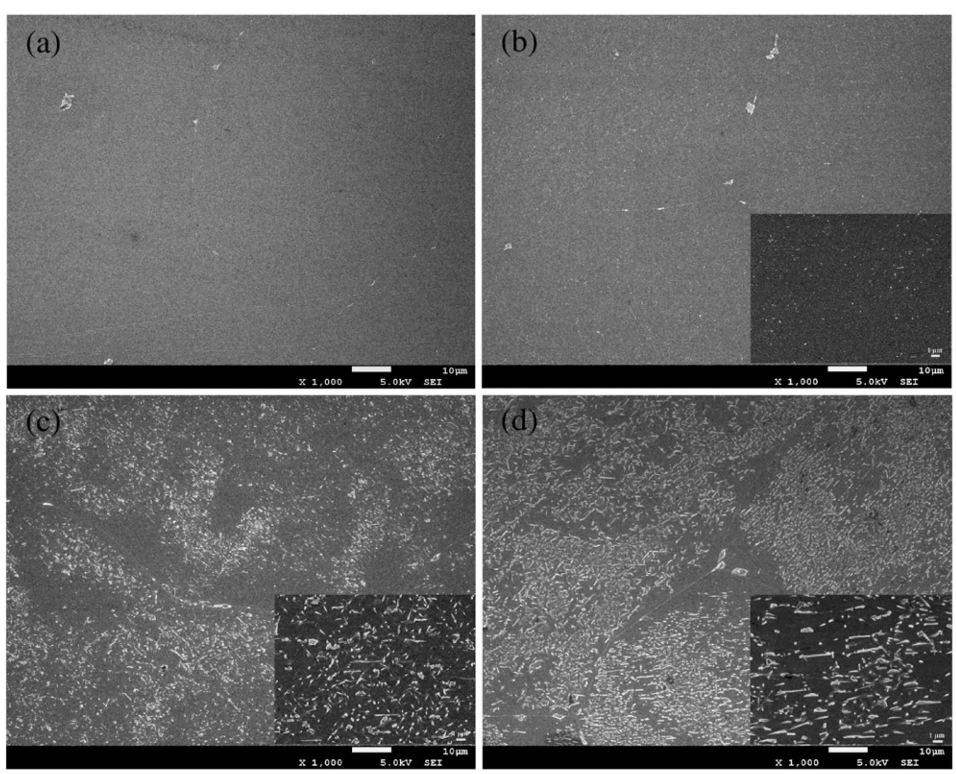

Fig. 2. SEM images of Mg–5Sn alloys after aging treatment for 6 h (a), 20 h (b), 64 h (c) and 120 h (b) at 513 K.