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Microstructure and mechanical properties on aging behavior of Zn containing Mg–2Sn–0.4Mn alloy

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ABSTRACT

The effects of Zn addition were examined by observing the microstructure and measuring the mechanical properties of Mg–*x*Zn–2Sn–0.4Mn with different Zn contents. The addition of Zn to the Mg–2Sn–0.4Mn alloy caused the precipitation of secondary phases and an improvement in the mechanical properties. The aged alloys showed improved elongation at break, which led to a slight decrease in yield strength and ultimate strength. The results suggest that the formation of precipitates containing Zn affects the mechanical properties of the alloys.

1. Introduction

Magnesium alloys have the lowest density of existing common alloys and are very important for reducing the weight of transportation vehicles, such as automobiles and airplanes [1,2]. The applications of these magnesium alloys have been limited owing to their low ductility and corrosion resistance compared to other light materials. On the other hand, many studies have reported that the mechanical properties of Mg, Zn and Sn alloys are improved by the formation of intermetallic compounds, such as Mg_2Sn and $MgZn_2$ phases [3,4]. To determine the effect of a third or fourth element, several alloying elements have been studied, including RE (RE = rare earth elements), Ag and Mn [5,6]. Nevertheless, only limited applications are expected from Mg–RE alloys due to the high cost of rare earth elements. Therefore, it is necessary to assess promising magnesium alloys with excellent elevated-temperature mechanical properties that do not use rare earth elements. Many studies have been conducted to improve the mechanical properties of Mg alloys. This suggests that the mechanical properties, particularly the ductility, of these developed Mg–Sn based alloys are still not high enough to be more competitive for engineering applications [7,8]. The addition of Zn could enhance the ductility and precipitation strengthening by the refinement and homogeneous dispersion of secondary phases in the as-cast Mg–Sn based alloys [9,10]. From this point, zinc is attractive for further improving the mechanical properties of as-cast Mg–Sn–Mn alloys. Therefore, the mechanical properties and precipitation behavior of Mg–*x*Zn–2Sn–0.4Mn alloys with various Zn contents were examined.

2. Materials and methods

Alloy ingots with a nominal composition of Mg–*x*Zn–2Sn–0.4Mn were prepared from high purity Mg (>99.95%), Zn (>99.9%), Sn (>99.9%) and Mn (>99.9%) by melting in an electric resistance furnace at approximately 1013 K under a mixed atmosphere of CO_2 and SF_6. Heat-treatment of the cast ingot was performed in vacuum. The cast ingot was a solid solution and was aged as shown in Table 1. The phase identification and microstructural assessment of the as-cast and aged alloys were carried out by X-ray diffraction (XRD, Rigaku DMAX 2500) and scanning electron microscopy (SEM, HITACHI S-4300SE), respectively. XRD was conducted using Cu-Kα operated at 40 mA and

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Table 1
Chemical compositions and experiment conditions.

Alloy composition					Solid solution	Age hardening
Samples	Zn	Sn	Mn	Mg	653 K for 12 h	453 K for 1, 15, 43, 70, 87, 95, 112, 134, 146, and 160 h
Z3 alloy	3.45	2.21	0.38	Bal.		
Z6 alloy	6.33					
Z10 alloy	10.28					
Z15 alloy	15.67					

40 kV, and a step size of 20°–90°2θ at 3° increments and a 1 min dwell time at each step. SEM was conducted to examine the microstructure of the different alloys, the different phases present, and the effects of the different thermal treatments on microstructural evolution. The TEM specimens were prepared by mechanical thinning and polishing followed by ion-milling. A JEOL-3010 and FEI Titan 80–300, both operating at 300 kV, were used for bright field (BF) imaging. Energy dispersive spectroscopy (EDS) was used to obtain the chemical compositions from a local area of the specimens. The microhardness was measured using a Rockwell hardness (HRB) tester; the data was converted to HV units. The HRB was measured at a minimum of ten points to reduce the error. Tensile testing was performed using a universal tensile machine at room temperature (RT) and at 423 K at a strain rate of 10^{-3} s^{-1}.

3. Results and discussion

The phase diagrams of the quaternary Mg–xZn–2Sn–0.4Mn alloys were calculated using Pandat™ to understand the phase formation and identify the trends of the solidification pathway, as shown in Fig. 1. The solidification pathway of Mg–xZn–2Sn–0.4Mn was slightly different from that of the Mg–3Zn–2Sn–0.4Mn alloys. The solidification sequence of the Mg–3Zn–2Sn–0.4Mn and Mg–15Zn–2Sn–0.4Mn alloys was as follows: L → L + α-Mg → α-Mg → α-Mg + MnZn(CBCC) → α-Mg + MnZn + Mg_2Sn → α-Mg + MnZn + Mg_2Sn + MgZn phases, whereas the solidification sequence of the Mg–15Zn–2Sn–0.4Mn alloy was as follows: L → L + α-Mg → L + α-Mg + MnZn(CBCC) → α-Mg + MnZn + Mg_2Sn + MgZn phases. These results show that the liquidus temperature decreased with increasing Zn content. The key factor is the precipitation of secondary phases, such as MgZn and Mg_2Sn. To investigate the phase fraction on temperature, Fig. 1(b) and (c) shows the thermodynamic results of the Mg–xZn–2Sn–0.4Mn alloys in the cooling process. The amount of MgZn and Mg_2Sn phase and precipitation temperature increased with increasing Zn content, as shown in Fig. 1(a) and (b).

Fig. 2 shows the microstructures of the casted Mg–xZn–2Sn–0.4Mn alloys. Coarse particles are present at the α-Mg grain boundaries, which become larger with increasing Zn content. Fig. 3 shows the XRD patterns of the as-cast alloys. The main phases in the Mg–Zn–Sn alloys reported were Mg_2Sn and MgZn. Similar to a previous study, the casted Mg–xZn–2Sn–0.4Mn alloys were composed mainly of α-Mg, Mg_2Sn and MgZn. EDS and XRD suggested that the particles in the Mg–xZn–2Sn–0.4Mn alloys were mostly Mg_2Sn phases with a small amount of MgZn phases. This suggests that the size of the Mg_2Sn phases became coarser with increasing Zn content, indicating that the solubility of Sn in Mg varied with the Zn content, as shown in Fig. 1(a). This result was also reported elsewhere [11].

Fig. 4 shows the age-hardening behavior of the Mg–xZn–2Sn–0.4Mn alloys. The Mg–xZn–2Sn–0.4Mn alloys exhibited a hardening response. At the initial stages of aging, the *Hv* generally increased with increasing aging time. After reaching the P*Hv*, the hardness decreased gradually due to over-aging. With increasing

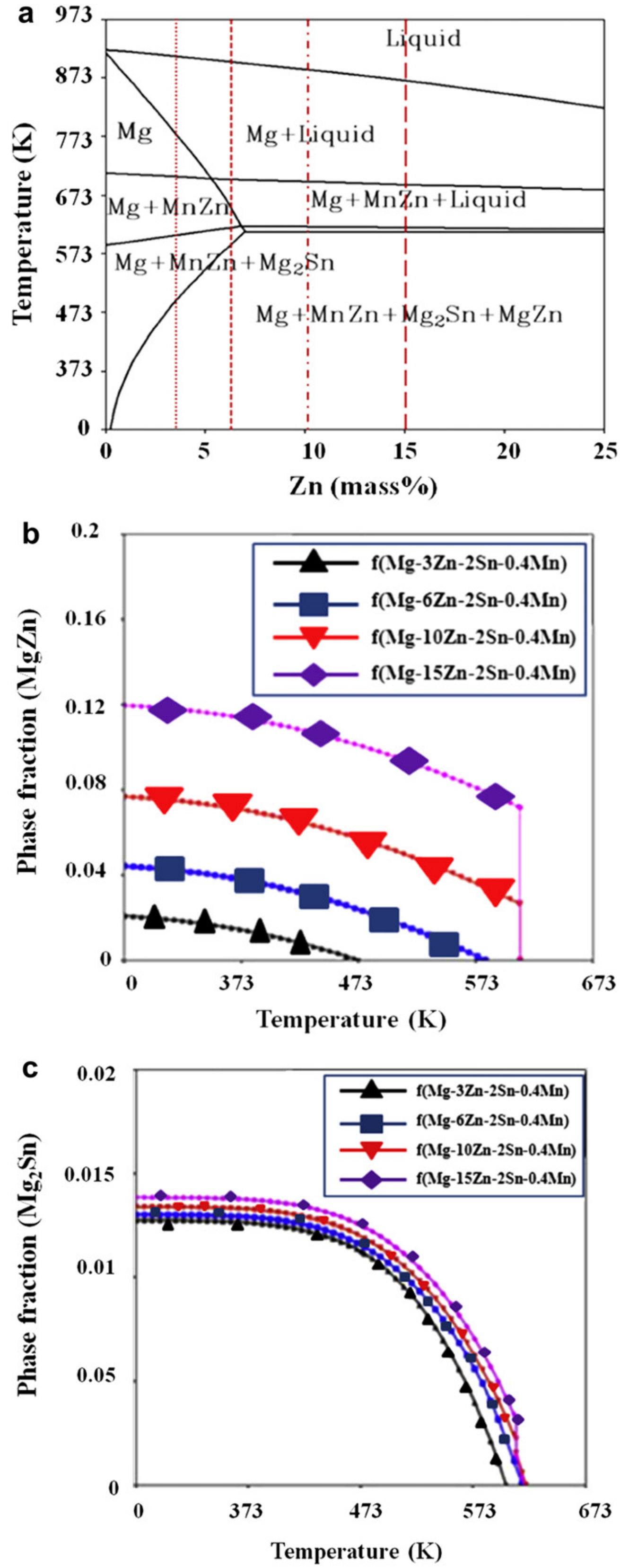

Fig. 1. The calculated data by Pandat program (a) equilibrium phase diagram of Mg–xZn–2Sn–0.4Mn, (b) volume fraction of (b) MgZn phase, and (c) Mg_2Sn phase.