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Microstructural Analysis of AM50/Mg_2Si Cast Magnesium Composites

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Abstract

AM50/Mg_2Si composites containing 5.7 wt. % and 9.9 wt. %. of Mg_2Si reinforcing phase were prepared successfully by casting method. The microstructure of the cast AM50/Mg_2Si magnesium matrix composites was investigated by light microscopy and X-ray diffractometry (XRD). The microstructure of these composites was characterized by the presence of α-phase (a solid solution of aluminium in magnesium), $Mg_{17}Al_{12}$ (γ-phase), Al_8Mn_5 and Mg_2Si. It was demonstrated that the Mg_2Si phase was formed mainly as primary dendrites and eutectic.

Keywords: AM50 magnesium alloy, Mg_2Si, Magnesium silicide, Metal matrix composites

1. Introduction

Magnesium and its alloys owing their low density and relatively good mechanical properties have been widely used as structural materials mainly in automotive and aerospace industries. Advantageous strength to weight ratio of magnesium alloys and their excellent castability make them good candidates to use in die casting which assure good shape reproducibility in the final products. Recycling of these materials is much more convenient than recycling of plastics [1-4].

However, magnesium alloys also have a number of undesirable properties such as poor wear resistance, high chemical reactivity and poor corrosion resistance that have limited their applications in many branches of industry. Therefore, the improvement of the properties of magnesium based materials is needed [1-3,5]. Fabrication of magnesium alloy matrix composites with various reinforcing constituents is one way to achieve this goal [6].

It has been shown that the magnesium matrix composites with Mg_2Si particles have a high potential because Mg_2Si exhibits interesting physical and mechanical properties [6]. The intermetallic compound, magnesium silicide, has a relatively high melting temperature (1085ºC), a low density (1.99 g/cm^3), a low thermal expansion coefficient (7.5×10^{-6} K^{-1}), a high hardness (4.5×10^9 N m^{-2}) and a reasonably high elastic modulus (120 GPa) [7-12].

The addition of Si to molten magnesium lead to the formation Mg_2Si phase in situ [6,13,14]. According to the Mg-Si equilibrium phase diagram [15] the maximum solubility of Si in Mg is only 0.0033 wt.% at 639°C, and eutectic is formed at 1.48 wt. % of Si and at a temperature of 637°C. For hypereutectic Mg-Si alloys the primary Mg_2Si phase has dendritic or polygonal shapes, while the Mg phase surround this constituent. On the other hand, the Mg+Mg_2Si eutectic is formed as fully divorced with rod-like Mg_2Si distributed in the continuous matrix. Various characteristics of Mg/Mg_2Si composites, especially mechanical properties, corrosion resistance and castability, are dependent on a form of Mg_2Si in which it exists in a particular material [10,14,16-19]. Thus, microstructural characterization of Mg/Mg_2Si composites is of major importance. The present work is focused on the microstructure of magnesium matrix composites with Mg_2Si, fabricated on a basis of AM50 alloy. The microstructure of AM50/Mg_2Si was investigated by light microscopy (LM) and phase identification was performed by X-ray diffraction method (XRD). Thermodynamic calculations were curried out to support experimental data.

2. Experimental materials and procedures

The composition of AM50 magnesium matrix alloy is listed in Table 1. To fabricate Mg-Al/Mg_2Si composites AM50 alloy ingots were re-melted at 680ºC and then a desired amount of a pure silicon powder was added into the melted alloy into a crucible. The composites were gravity cast into a metal mould. For comparison purposes, AM50 alloy was cast at the same conditions. The silicon content in resulted composites was determined by atomic absorption spectrometry. The content of Mg_2Si in the fabricated composites was calculated with the assumption that silicon exists in them only as Mg_2Si. Two kinds of composites containing 5.7 wt. % and 9.9 wt. % of Mg_2Si were fabricated.

Table 2.
Chemical composition of AM50 alloy according to ASTM B93-94

Chemical composition [wt.%]*)							
Alloy	**Al**	**Mn**	**Zn**	**Si**	**Fe**	**Cu**	**Mg**
AM50	4.5-5.3	0.28-0.5	max 0.02	max 0.05	max 0.004	max 0.008	rest
*) **Mg rest**							

For LM examinations, composite samples were ground on waterproof sandpaper (a grinding size down to 4000) and then polished on polishing cloth with a lubricant containing 0.1μm diamond particles (Buehler, U.S.A.). Samples were etched in 1% solution of concentrated nitric acid in ethanol for 5 second. An Olympus GX51 light microscope equipped with an Olympus UC30 camera was used for LM observations. XRD measurements were performed on a Brucker D8 Advance diffractometer. $Cu_{K\alpha}$ X-ray radiation was applied. Phase identification was conducted with a help of PDF4+ (2011) data base (The International Centre for Diffraction Data, Denver, U.S.A.). For thermodynamic calculations Thermo-Calc Software System from Thermo-Calc Software AB (Stockholm, Sweden) was used.

3. Results and discussion

Fig. 1 presents a typical microstructure of the as-cast AM50 magnesium alloy. The following microstructural constituents are visible: (i) primary α-phase (i.e. a solid solution of alloying elements in magnesium), (ii) divorced eutectic α+γ (where γ-phase is consisted of $Al_{12}Mg_{17}$ intermetallic compound) and (iii) most likely Al_8Mn_5. The observed microstructure is a result of strong microsegregation of alloying elements, which is characteristic for most of magnesium alloys solidifying in non-equilibrium conditions.

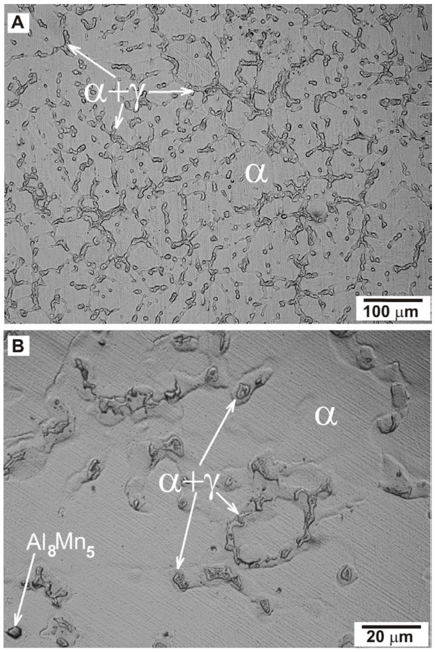

Fig. 1. Microstructure of as-cast AM50 magnesium alloy (LM).

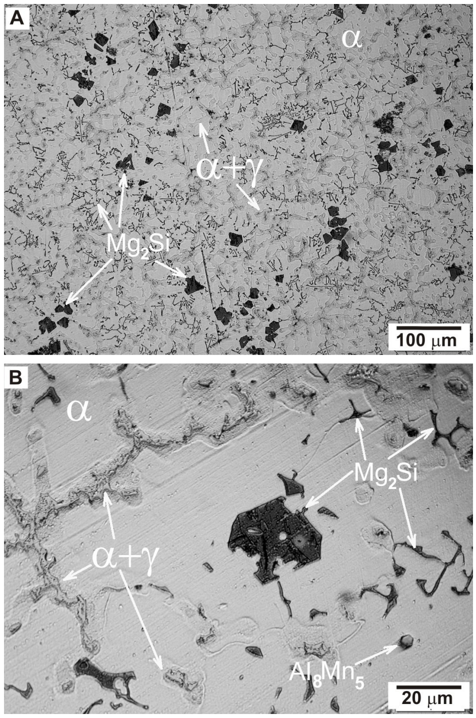

Fig. 2. Microstructure of as-cast AM50/5.7 wt. % Mg_2Si magnesium matrix composite (LM)

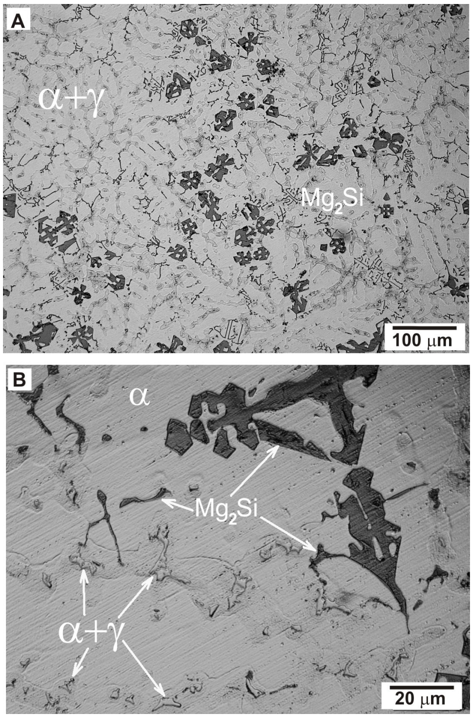

Fig. 3. Microstructure of as-cast AM50/9.9% wt. Mg_2Si magnesium matrix composite (LM)

The microstructures of the fabricated AM50/Mg_2Si composites containing 5.7 wt. % and 9.9 wt. % Mg_2Si are shown in Figs. 2 and 3, respectively. All microstructural constituents which are present in the parent alloy are also present the composites' matrix. In the both fabricated composites, two distinct morphologies of a Mg_2Si phase are observed. Namely, Mg_2Si is present in a form of relatively large (several μm) dendrites and eutectic. It comes from LM observations, that reinforcing phase is uniformly distributed in a whole volume of the matrix.

To get a better insight into the solidification process of the investigated materials, the phase diagram was calculated for the Mg-Si binary system at constant concentrations of Al and Mn which are equal to 5 wt. % and 0.45 wt. %, respectively. Calculations were performed for equilibrium conditions. A fragment of the phase diagram between liquidus and solidus temperatures is shown in Fig. 4. According to this diagram after the solidification the composite containing 5.7 wt. % Mg_2Si should be consisted of α + Mg_2Si + Al_8Mn_5, whereas the composite containing 9.9 wt. % Mg_2Si should be consisted of α + Mg_2Si + Al_3Mn_2. It should be noted that according to the equilibrium phase diagram the γ phase is formed from the solid state, as secondary precipitates, below solvus temperatures which are equal to 525.5K and 531.5K for the composites containing 5.7 and 9.9 wt. % of Mg_2Si, respectively. To analyze the solidification in non-equilibrium conditions, the solidification curve (Fig. 5) was calculated according to the Scheil model. The solidification starts from the formation of the primary Mg_2Si phase, like in the case of equilibrium conditions, but finishes with the ternary α+γ+Mg_2Si eutectic transition which is consistent with the observed microstructure (Fig. 3).

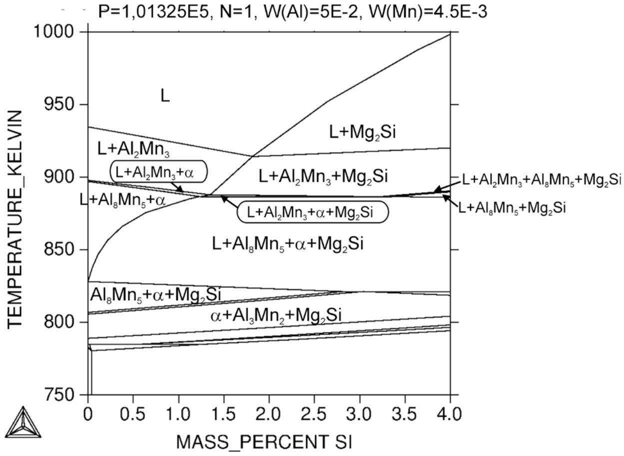

Fig. 4. Fragment of the Mg-Si phase diagram calculated at constant concentrations of Al (5 wt. %) and Mn (0.45 wt.%)

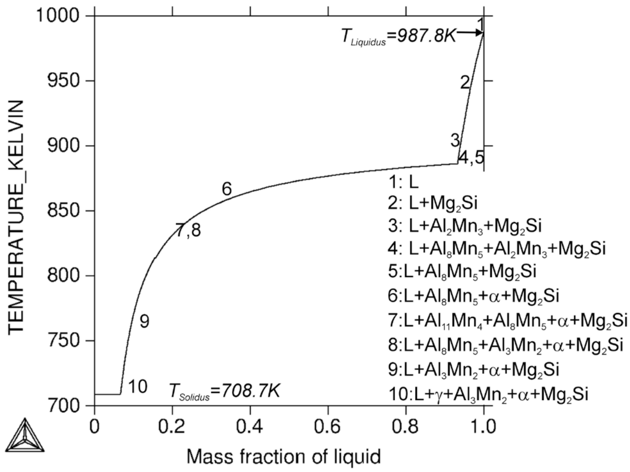

Fig. 5. Solidification curve of AM50/9.9wt.% Mg_2Si composite calculated according to the Scheil model.

In order to confirm the phase composition of the fabricated composites and the AM50 alloy, XRD analysis was performed. Fig. 6 shows X-ray diffraction patterns for the AM50 matrix alloy and the composites containing 5.7 and 9.9 wt. % of Mg_2Si. XRD data confirms the presence of α and γ phases as well as Al_8Mn_5 intermetallic compound in all materials. There are no reflexes originating from silicon which means that silicon reacted completely with magnesium forming Mg_2Si. Although, performed thermodynamic calculations indicated many changes in the composition of the Al-Mn phase, only Al_8Mn_5 intermetallic compound was identified in the AM50 alloy and the composites by XRD.

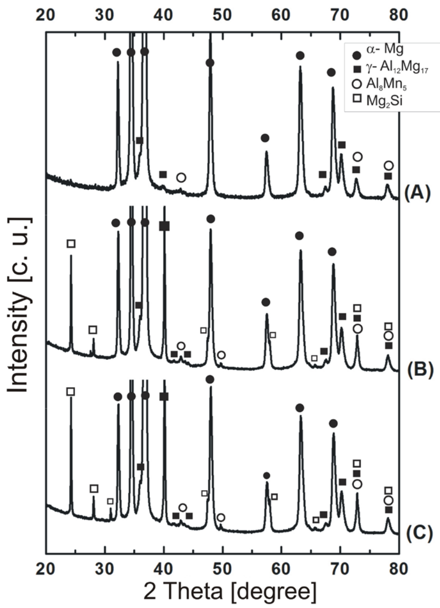

Fig. 6. X-ray diffraction patterns of (A) AM50 alloy and AM50/Mg_2Si composites containing (B) 5.7 wt. % and (C) 9.9 wt.% reinforcing phase

4. Summary

The microstructural analysis of the AM50 magnesium alloy and Mg-Al/Mg_2Si composites containing 5.7 and 9.9 wt. % reinforcing phase was presented. The results revealed that the microstructure of as-cast AM50 alloy was characterized by the presence of α - phase and eutectic α + γ (where γ is $Mg_{17}Al_{12}$) as well as Al_8Mn_5. The addition of silicon to the AM50 alloy caused the formation of the primary Mg_2Si phase and the ternary eutectic α+γ+Mg_2Si.The Mg_2Si phase was uniformly distributed in a whole volume of the matrix.

Acknowledgements

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