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Microstructural characterization and mechanical properties of Mg-xSn-Al-Zn alloys

B.H. Kim, J.J. Jeon, K.C. Park, B.G. Park, Y.H. Park, I.M. Park*
Department of Material Science and Engineering, Pusan National University
San 30 Jangjeon-dong, Geumjeong-gu, Busan 609-735, Korea
* Corresponding author: E-mail address: kjbshh@pusan.ac.kr

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ABSTRACT

Purpose: In this study, the microstructure and mechanical properties of as-cast Mg-xSn-Al-Zn alloys were investigated.

Design/methodology/approach: Ingot was fabricated by a squeeze cast. The alloys were induction melted at 750ºC in a mild steel crucible under CO_2+2%SF_6 mixed gas atmosphere and cast into a permanent mould coated with boron nitride spray held at approximately 350ºC . Tensile tests were carried out at room temperature in a screw-driven tensile testing machine and crosshead speed was 0.2 mm/min. Microstructural observation was carried out using a optical microscope (OM) and a scanning electron microscope (SEM) equipped with energy dispersive X-ray spectrometer (EDS).

Findings: It is found that the tensile strength and elongation decreased at room temperature increased with Sn concentration. As a consequence, 5wt% Sn addition was the one exhibiting the best tensile properties at room temperature. The micro-hardness of the alloy continuously increased with increasing the Sn concentration.

Practical implications: The investigations of microstructure of commercially magnesium alloys are important for achieving desired mechanical behaviour of the material.

Originality/value: The fracture behaviors of magnesium alloys are investigated.

Keywords: Mechanical properties; Precipitation hardening; TAZ

PROPERTIES

1. Introduction

Magnesium alloys have great potential for high performance structural applications because of their low density and high specific strength. Mg-Al based alloys, such as AM60B and AZ91D, which exhibit a good balance of strength and ductility are used extensively in power-train applications such as transmission housing and crankcases [1-2]. These applications require high performance and microstructural stability at elevated temperature (>150ºC). However, Mg-Al based alloys have poor creep resistance at temperature above 120ºC and show large decrease in strength at elevated temperature due to the thermally unstable phase, $Mg_{17}Al_{12}$(β) [3-4]. In order to improve mechanical properties of the magnesium alloys at elevated temperature, the formation of thermally stable precipitates or dispersoids are required.

A Mg-Sn system is known to be the one whose properties are mainly controlled by a precipitation process [5-6]. According to the binary phase diagram [7], the solubility of Sn in α-Mg matrix drops sharply from 14.85wt.% at the eutectic transformation temperature 561ºC to 0.45wt.% at 200ºC. This provides a fundamental basis for improving the mechanical properties of these alloys through ageing. It shows some positive characteristics in terms of potential creep resistance due to the formation of a high temperature stable phase Mg_2Sn (meting point: 770ºC). It is typically distributed around the grain boundaries. Also, the mush zone temperature range of Mg-Sn binary alloys is much narrower than Mg-Al and Mg-Zn binary alloys. As a result, the casting defects, such as dispersed shrinkage and hot tearing are less severe in Mg-Sn alloys than other ones.

Table 1.
Material designation and chemical compositions (wt.%)

Metallurgy Designation	Alloy	Mg	Sn	Al	Zn
TAZ551	Mg-5Sn-5Al-1Zn	Bal.	4.98	4.99	0.51
TAZ651	Mg-6Sn-5Al-1Zn	Bal.	6.01	4.97	0.50
TAZ751	Mg-7Sn-5Al-1Zn	Bal.	6.89	5.02	0.51
TAZ851	Mg-8Sn-5Al-1Zn	Bal.	7.03	5.04	0.49

This study was focused on the investigation of the microstructure and mechanical properties of as-cast Mg-Sn-Al-Zn alloys.

2. Experiments

Materials used in this study were Mg-xSn-5Al-1Zn alloy systems and the nominal compositions and material designation are listed in Table 1. Starting materials were commercial alloy of AZ31, Sn (99.9%), and Al (99.9%). Ingot was fabricated by a squeeze cast. The alloys were induction melted at 750ºC in a mild steel crucible under CO_2+2%SF_6 mixed gas atmosphere and cast into a permanent mould coated with boron nitride spray held at approximately 350ºC. The pressure of plunger was 70 MPa and was kept for 60s.

Microstructural observation was carried out using a optical microscope(OM) and a scanning electron microscope(SEM) equipped with energy dispersive X-ray spectrometer(EDS). Volume fractions of precipitates were measured by an image analyzer. A phase analysis was carried out using X-ray diffraction with Cu Kα radiation. Tensile tests were carried out at room temperature in a screw-driven tensile testing machine and crosshead speed was 0.2mm/min. Round tension test specimens were used and had dimensions of 30mm in gauge length and 4mm in the reduced section diameter. Tensile fracture surfaces of the alloys were examined by SEM. Hardness was measured using a Micro Vickers hardness tester.

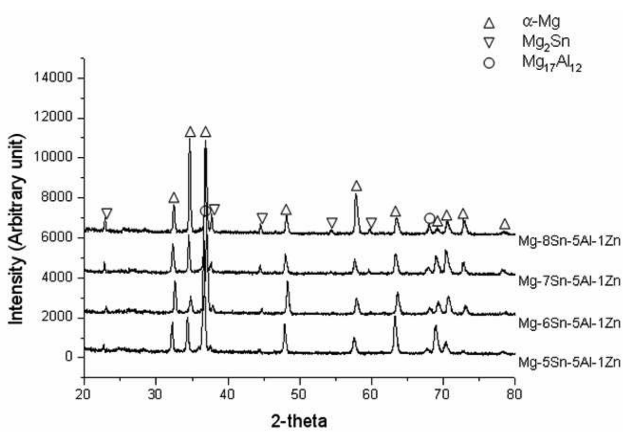


Fig. 1. XRD patterns of Mg-xSn-5Al-1Zn alloys

3. Result and discussion

3.1. Microstructure

The results of X-ray diffraction analysis are shown in Fig. 1. The alloys consisted of expected α-Mg, Mg_2Sn and $Mg_{17}Al_{12}$ phases. The peak intensity for the Mg_2Sn particle increased with the increase of Sn content. It was in agreement with the previous results in the Mg-Zn-Sn alloy system [8].

Fig. 2 shows SEM micrographs taken from the as-cast alloys. The as-cast microstructures of the alloys were similar, that is, they consisted of the α-Mg matrix and intermetallic compounds of Mg_2Sn and $Mg_{17}Al_{12}$ which were formed at α-Mg matrix. With increasing the Sn content, the amount of Mg_2Sn phases were increased and the size was coarsened. In. Fig. 2(d) shows that the alloy was composed of the primary α-Mg matrix, a eutectic α-Mg+ Mg_2Sn, $Mg_{17}Al_{12}$ and coarser Mg_2Sn. The volume fraction of the Mg_2Sn phase increased (Fig. 3) and tended to be coarsened as clearly shown in Fig. 2(d).

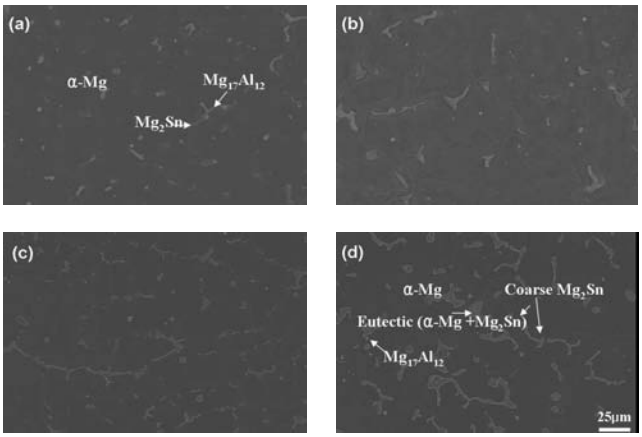


Fig. 2. SEM microscopy microstructures of the Mg-xSn-5Al-1Zn alloy (a) 5wt% Sn (b) 8wt% Sn

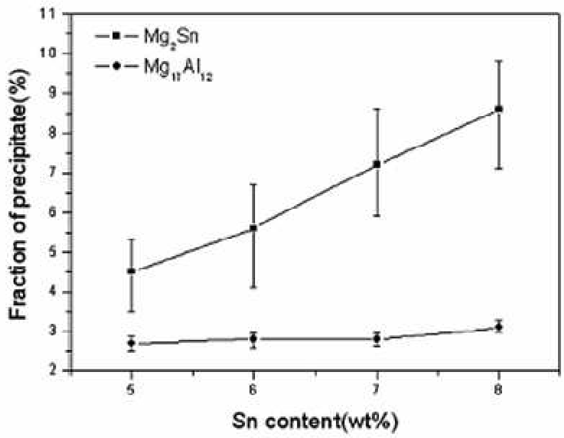


Fig. 3. Mg-xSn-5Al-1Zn alloys volume percentage of precipitates of Mg_2Sn and $Mg_{17}Al_{12}$

3.2. Mechanical properties

Fig. 4 shows ultimate tensile strength and elongation of the alloys at room temperature. The Sn addition had significant effect on the tensile properties. The ultimate tensile strength was increased by 21% and the elongation by 58% when compared with the 8wt% Sn and optimum mechanical property combination was obtained at the 5wt% Sn.

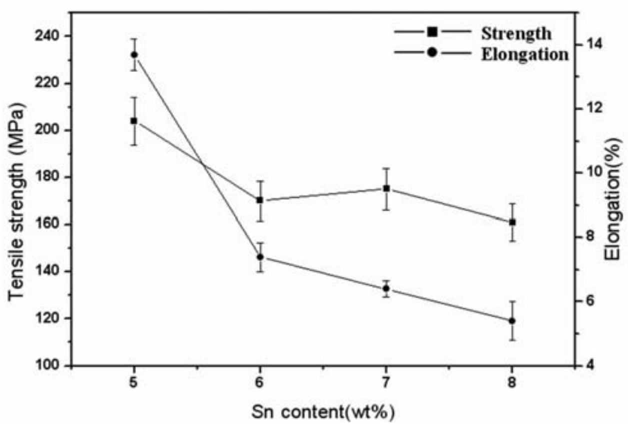


Fig. 4. Tensile properties of Mg-xSn-5Al-1Zn alloys in as-cast at room temperature

The discrete Mg_2Sn phase was precipitated mainly at grain boundaries. It might suppress the movement of dislocations and played an important role in the improvement of the tensile strength. Therefore, Mg_2Sn phase should have a positive effect on the tensile strength. However the excess Sn caused the coarse Mg_2Sn phase and tended to form semi-continuous network on the grain boundary [9]. The presence of these large intermetallic phases and the semi-continuous network morphology promoted the initiation and propagation of cracks and led to an adverse effect on the strength and ductility. In this study, the addition of Sn decreased the tensile strength at room temperature. This meant that the negative effect of the Sn addition was predominant.

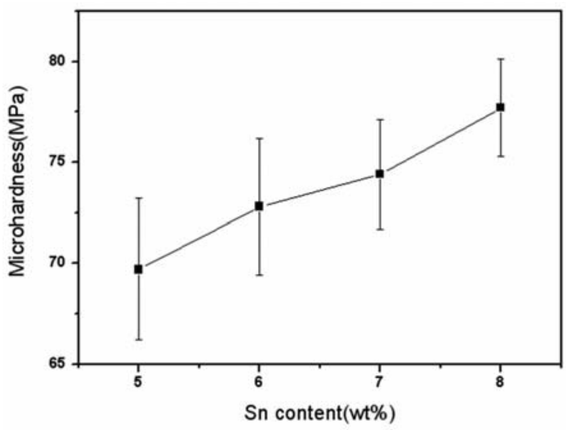


Fig. 5. Micro hardness of Mg-xSn-5Al-1Zn alloys in as-cast (x: 5, 6, 7, 8 wt%)

Fig. 5 shows that the micro-hardness of the alloy continuously increased with the addition of Sn. The micro-hardness of the 8wt% Sn addition was increased by 14.2 % when compared with 5wt% Sn. Mg_2Sn is a hard (~119HV) and brittle phase, which contributes to strengthen the matrix [10]. This explains the continuous increase in micro-hardness of the alloys with increasing the Sn content.

3.3. Fracture behaviours

Fig. 6 shows optical micrographs of the vertical section of the test bar fractured by tensile test. The secondary crack perpendicular to the main crack was observed and propagated through the α-Mg matrix. Fig. 7 shows SEM images of the vertical section of the tensile test. Cracks were initiated preferentially in the second phase fracture. Therefore, crack propagation seemed to proceed by crack bridging. This meant that increased Sn content formed more second phase so that crack was initiated more easily.

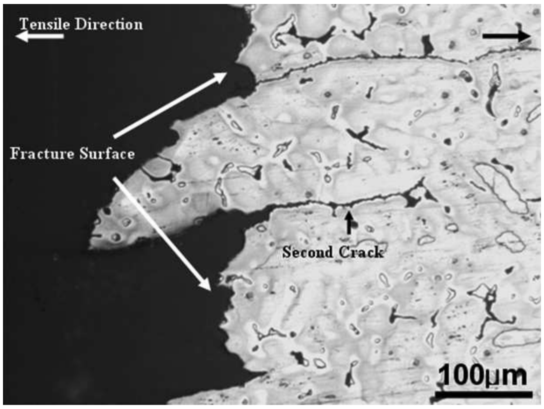
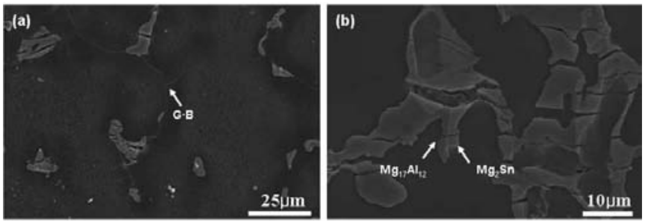


Fig. 6. Optical result for the vertical section of the TAZ551 specimen failed in tensile test

The initiation of microcracks can be greatly influenced by the presence and nature of the second phase [11]. A common situation is for the particle to crack during deformation. Resistance to cracking is improved if the particle is well bonded to the matrix. The dispersion of second phase particles is easily cut by the dislocations, then there will be planar slip and relatively large dislocation pile-ups will occur. This will lead to high stress, easy initiation of microcracks and brittle behaviour [12]. Also, the bigger particle size is, the more easily particle can be fractured. Increasing the Sn content resulted in the increase of the size of the second phase. This could explain the decrease of ductility with increasing the Sn content.

Cleavage, quasi-cleavage and inter-granular fractures are main modes of magnesium alloys [13-14]. In the fracture modes, no obvious inter-granular cracks were observed in the alloys containing Sn in this study. Chen Jihua et al. [15] recently examined the effects of Sn addition on microstructure and mechanical properties of ZA alloys. They reported that the addition of Sn led to refinement and suppression of the divorced MgZn eutectic.



G·B: Grain Boundary

Fig. 7. SEM image for the vertical section of the TAZ551 specimen failed in tensile test

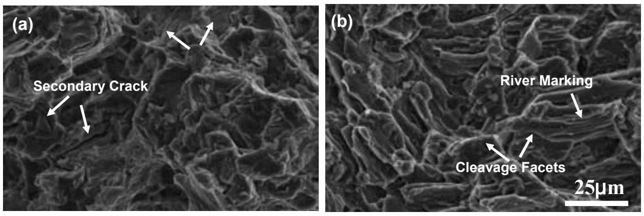


Fig. 8. Factography of Mg-xSn-5Al-1Zn alloys by tensile fracture: (a) 5wt%Sn (b) 8wt%Sn

Therefore, it seemed to be the result of refinement and suppression of $Mg_{17}Al_{12}$ phase. Fig. 8 shows the SEM images of the tensile fracture surfaces in the alloys tested at the room temperature. As shown in Fig. 8(a), the surface was characterized by cleavage-type facets, dimples and secondary crack. The flat facets were formed along the interface between the Mg matrix and $Mg_{17}Al_{12}$ and the secondary cracks perpendicular to the main crack was within the matrix. The cleavage facets exhibited "river marking" [12]. Therefore, characteristic of cleavage fracture and void coalescence was the main mechanism of the fracture. As shown in Fig. 8, the portion of cleavage facet was increased with increasing the Sn content. This phenomenon also proved the decrease of ductility as increasing the Sn content.

4. Conclusions

The Sn content was systemtically changed in the Mg-xSn-Al-Zn system and the microstructure and mechanical properties were investigated. From the observation, the following conclusions can be drawn.

(1) Mg-xSn-Al-Zn alloys mainly composed of primary α-Mg matrix, $Mg_{17}Al_{12}$ and Mg_2Sn phase, and the volume fraction of the Mg_2Sn phase increased with the Sn concentration.
(2) The tensile strength and elongation decreased at room temperature increased with Sn concentration. As a consequence, 5wt% Sn addition was the one exhibiting the best tensile properties at room temperature. The micro-hardness of the alloy continuously increased with increasing the Sn concentration.
(3) The dimple and cleavage facet were dominant mechanisms of these alloys tested at room temperature and portion of cleavage facet was increased with the increment of Sn at room temperature.

Acknowledgements

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