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Microstructural and Mechanical Characteristics of Wrought Mg-Sn-Zn Alloys

J.M Kim[†], J.S. Park

Division of Advanced Materials Engineering, Hanbat National University, Daejeon, 305-719 Korea

Abstract Precipitate formations and grain size variations in various Mg-Sn-Zn alloys have been investigated and their effects on the tensile properties and sheet metal formability were evaluated. MgSn and MgZn precipitates were observed in the alloy sheets, however any clear difference in morphology or size for the precipitates could not be found even though MgSn precipitates tend to be larger than MgZn. The highest formability in terms of conical cup value was found in the Mg-4 wt%Sn-2 wt%Zn where the high tensile elongation and the reduced grain coarsening at elevated temperatures were observed.

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Key words: *Mg alloy, precipitate, grain size, sheet metal forming*

1. Introduction

As environmental issues become more important, much attention has been paid to magnesium alloys. Even though most of magnesium alloy parts are currently fabricated by casting process, the application of wrought process such as sheet metal forming becomes more active. Mg-Al or Mg-Al-Zn magnesium alloys like AZ31 have been widely used for wrought parts because of the excellent mechanical properties and work formability. However, more complex shaped magnesium parts become common and there is a demand for new Mg alloys with higher formability. Mg-Zn-(Zr) alloys are not used as much as Mg-Al-(Zn) alloys, but the alloys possess the good formability and may be alternative for complex shaped parts. Recently, it has been also found that a small amount of Sn addition increases the ductility of Mg-Zn-Zr alloy sheet at an elevated temperature [1]. Therefore, Mg-Sn-Zn alloy sheets containing various Sn and Zn contents haven been investigated in this research.

Sheet metal forming process for magnesium alloy parts are often carried out at elevated temperatures to enhance the ductility of the material that is necessary for successful forming, and dynamic recrystallization can easily take place in Mg alloys at hot working processes, resulting in some influence on the mechanical properties and formability of sheets. It has been known that solute atoms may segregate at grain boundaries and effectively hinder the recrystallization by acting as obstacles to their migration [2]. If solute atoms are precipitated to form fine phases in the matrix, the recrystallization can be more effectively hindered [3,4]. However the effects of precipitates on recrystallization are complex and also dependent on the particle size. Large precipitates, which are larger that 1μm, may rather promote the recrystallization by providing ideal nucleation sites for nuclei[5].

2. Experimental Procedures

Chemical compositions of experimental Mg-Sn-Zn alloys are shown in Table 1. Pure (99.9%) Mg, Sn, and Zn metals were used for melting and casting under a protective $SF_6 + CO_2$ gas atmosphere. The prepared liquid metal was

[†]E-mail : jmk7475@hanbat.ac.kr

Table 1. Chemical compositions of experimental Mg-Sn-Zn alloys (wt.%)

Alloy	Sn	Zn	Mg
Mg-2%Sn-2%Zn	2.03	2.35	Balance
Mg-2%Sn-4%Zn	1.80	3.92	"
Mg-4%Sn-2%Zn	3.51	2.14	"
Mg-4%Sn-4%Zn	3.46	4.18	"

poured into a metallic mold to produce cylindrical castings, and the cast ingots were machined into rods with a diameter of 100 mm for extrusion. Then the rods were deformed into plates with 10 mm thickness through the extrusion processing at 300°C. Finally, repeated hot rollings of the plates were conducted until the final thickness reached to 2 mm. The reduction ratio was carefully controlled (low strain level) not to bring about non-homogeneous microstructure such as shear band [6].

The tensile test was carried out with the as-rolled specimens at room temperature and 250°C, according to ASTM B 557 M. In the CCV (conical cup value) test, a circular sheet blank of 50 mm in diameter was placed on the top of a die with a conical cavity [7]. The sheet was deformed to fracture by the punch with a circular head, and the diameter of the top of the fractured cup was measured and used for CCV, according to JIS Z2249 standard. CCV tests were performed at 200-300°C, which cover the expected operation temperatures for sheet metal forming. The remarkable increase in formability of magnesium sheet alloys was observed in the temperature range from 200 to 225°C, due to the thermal activation of pyramid sliding planes in the HCP structure [8]. The microstructures were examined by using SEM (Scanning Electron Microscope) equipped with EDS (Energy Dispersive Spectrum) and TEM (Transmission Electron Microscope). TEM foil was prepared by a combination of mechanical polishing, electro-polishing, and final ion-milling.

3. Results and discussion

Fig. 1 shows typical SEM micrographs of the as-rolled Mg-Sn-Zn alloys. Microstructure of the Mg-Sn-Zn alloys mainly consists of primary Mg phase (matrix) and finely distributed second

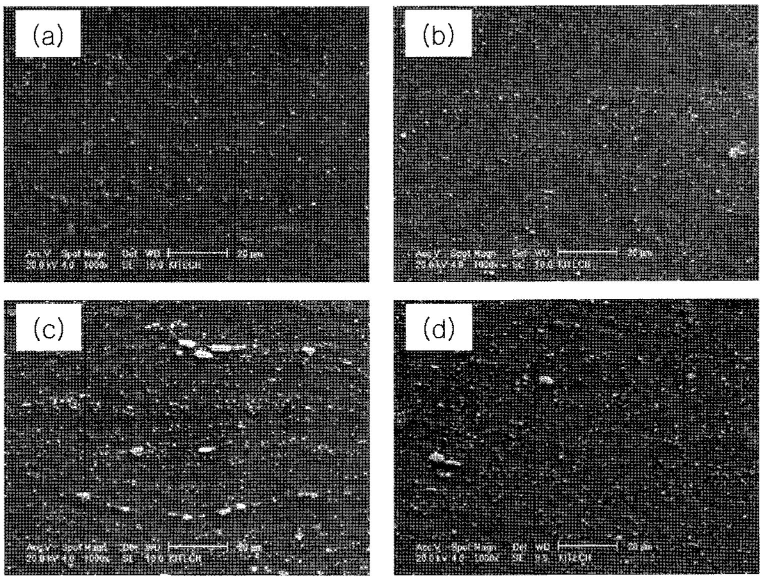

Fig. 1. Typical SEM micrographs of the as-rolled Mg-Sn-Zn alloys: (a) Mg-2%Sn-2%Zn (b) Mg-2%Sn-4%Zn (c) Mg-4%Sn-2%Zn (d) Mg-4%Sn-4%Zn.

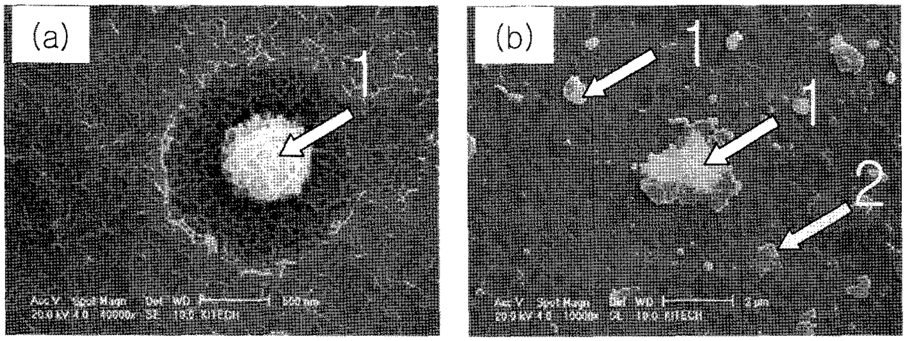

Fig. 2. MgSn (1) and MgZn (2) phases observed in the Mg-4%Sn-2%Zn (a), and Mg-2%Sn-4%Zn alloys (b).

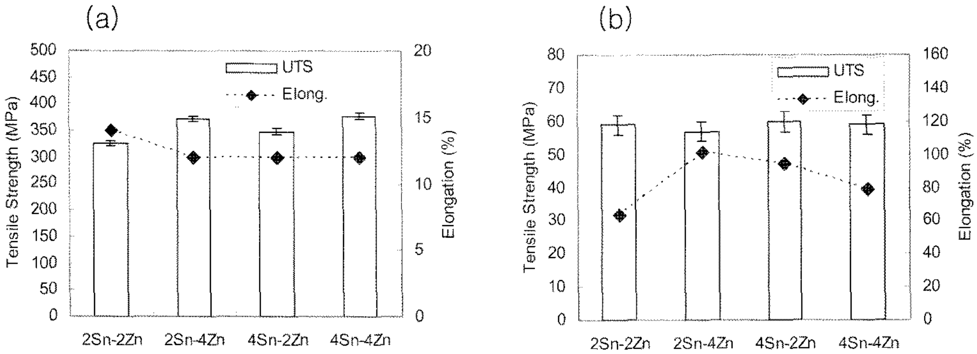

Fig. 3. Tensile properties of the as-rolled Mg-Sn-Zn alloys at room (a), and 250°C (b).

phases (white particles), and the amount of the second phases was generally increased with increasing the Sn content. As indicated in Fig. 2, MgSn and MgZn phases were observed in the specimens, however any clear difference between the two phases in terms of size and morphology could not be found.

Fig. 3 shows tensile properties of Mg-Sn-Zn alloy sheets with different Sn and Zn contents, conducted at room temperature and 250°C. It is to be noted that high contents of Zn alloys exhibited higher tensile strength than low Zn alloys at room temperature, regardless of Sn content. The amount of precipitates is greatly affected not by Zn but by Sn content, as indicated in Fig. 1. Therefore, the strength at room temperature in high contents of Zn alloy is higher because of the high solid solution strengthening effect of Zn atoms in the magnesium matrix. Considering that solid solution strengthening effect is generally increased with increase of the atomic radius difference between magnesium (matrix) and solute atoms. Zn solute is expected to be much more effective than Sn solute. The tensile strength at 250°C was not clearly influenced by Sn or Zn contents, but the elongations of Mg-2%Sn-4%Zn and Mg-4%Sn-2%Zn alloys were apparently larger than others.

Sheet metal formability of alloy sheets, which is inversely proportional to measured conical cup value, was evaluated at some elevated temperatures in Fig. 4. Even though there are some variations depending on the test temperature, it appears that the highest formability (the smallest CCV) was obtained in the Mg-4%Sn-2%Zn alloy. This alloy composition demonstrated high tensile

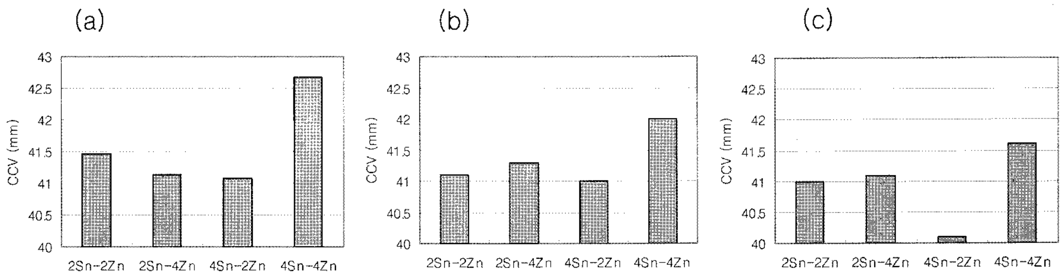

Fig. 4. Conical cup value of the as-rolled Mg-Sn-Zn alloy sheets at different temperatures at 200 (a), 250 (b), and 300°C (c).

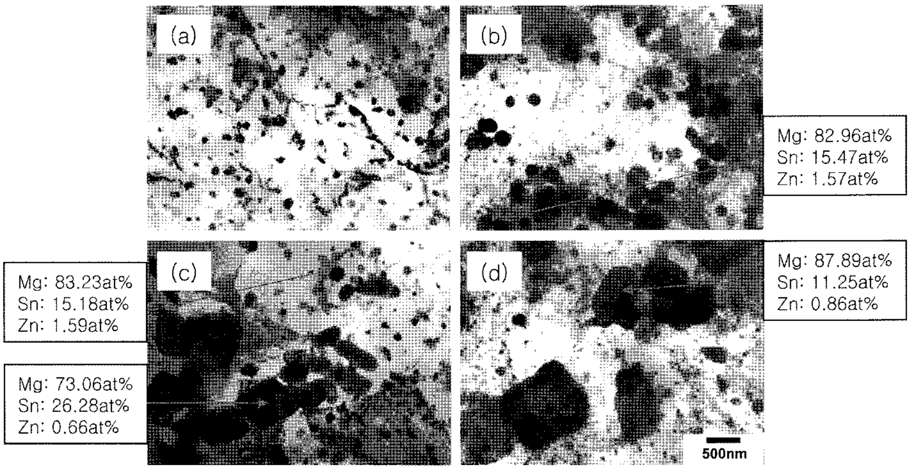

Fig. 5. TEM micrographs of fine MgSn and MgZn precipitates observed in the Mg-2%Sn- 2%Zn (a), Mg-2%Sn-4%Zn (b), Mg-4%Sn-2%Zn (c), Mg-4%Sn-4%Zn (d) alloy sheets.

elongation at 250°C, but not as high as Mg-2%Sn-4%Zn. Another reason to possess high formability might be the promoted recrystallzation by large precipitates. The extensive microstructural evolution by dynamic recrystallization may reduce the stress level during the deformation and improve the formability of the alloy. TEM micrographs indicate that only very fine precipitates were found in the Mg-2%Sn-2%Zn alloy, while relatively larger precipitates were also found in other alloys (Fig. 5). The amount of precipitates, especially coarse particles with the diameter that is close to 1 μm, was larger in high Sn (4%Sn) alloys. The low formability was observed in the Mg-4%Sn-4%Zn alloy possibly because of its low ductility at an elevated temperature. Although MgSn precipitates tend to be larger than MgZn precipitates, it was not possible to discern one from the other by their size or morphology.

In order to investigate the coarsening phenomena of alloys, the as-rolled sheets were annealed at 300°C for 24 hours. The investigated alloys may be divided into two groups in terms of grain growth behaviors that are shown in Fig. 6. The average grain size of low Sn (2%Sn) alloys was significantly increased as compared to that of high Sn alloys after the annealing. The particle-limited grain size is inversely proportional to the volume fraction of fine particles[9], and it is postulated that the finer grain size was obtained in the high Sn alloys mainly due to more effectively hindered grain growth by large volume fraction of precipitates. Fig. 6(b) also

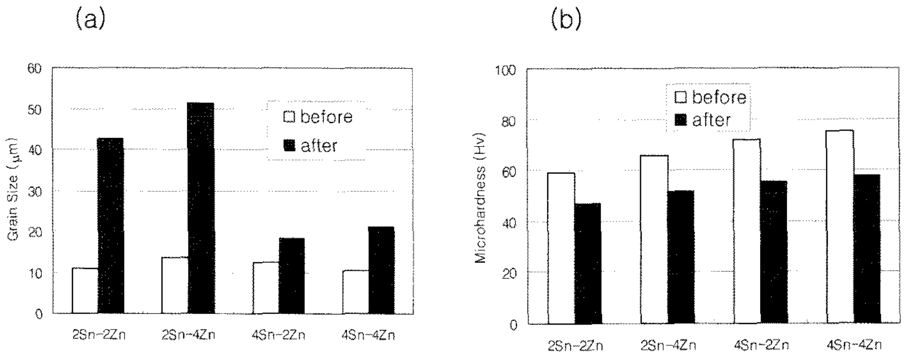

Fig. 6. Variations of grain size (a) and microhardness (b) of Mg-Sn-Zn alloy sheets before and after annealing at 300°C for 24hours.

shows that the micro-hardness of all the alloys was reduced by the annealing. Both of micro-hardness values before and after annealing are generally proportional to the amount of alloying elements. Although the tensile strength of Mg-2%Sn-4%Zn alloy was larger than that of Mg-4%Sn-2%Zn alloy, the hardness was found in reverse, may be owing to larger volume fraction of precipitates in the high Sn alloy.

Summary

Tensile properties and sheet metal formability of various Mg-Sn-Zn sheets were evaluated for the purpose of developing high formability magnesium alloys. Large precipitates were more frequently found in high Sn alloys compared to low Sn alloys, and grain growth at 300°C was significantly hindered in the high Sn alloys. Mg-4%Sn-2%Zn was found to be the most promising alloy because the sheet metal formability was the best in all the test temperatures.

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