Microstructure and Mechanical Properties of Mg-Zn Alloys

Young Sik Kim, Tae Kwon Ha

Abstract**—**Effect of Zn addition on the microstructure and mechanical properties of Mg-Zn alloys with Zn contents from 6 to 10 weight percent was investigated in this study. Through calculation of phase equilibria of Mg-Zn alloys, carried out by using FactSage® and FTLite database, solution treatment temperature was decided as temperatures from 300 to 400°C, where supersaturated solid solution can be obtained. Solid solution treatment of Mg-Zn alloys was successfully conducted at 380°C and supersaturated microstructure with all beta phase resolved into matrix was obtained. After solution treatment, hot rolling was successfully conducted by reduction of 60%. Compression and tension tests were carried out at room temperature on the samples as-cast, solution treated, hot-rolled and recrystallized after rolling. After solid solution treatment, each alloy was annealed at temperatures of 180 and 200°C for time intervals from 1 min to 48 hrs and hardness of each condition was measured by micro-Vickers method. Peak aging conditions were deduced as at the temperature of 200°C for 10 hrs. By addition of Zn by 10 weight percent, hardness and strength were enhanced.

Keywords**—**Mg-Zn alloy, Heat treatment, Microstructure, Mechanical properties, Hardness.

I. Introduction

PROPERTIES of magnesium make it appealing for a wide variety of applications, and significant growth has occurred in the area of die-cast components. This silvery-white metal is the eighth most abundant element, comprising 2.7% of earth's crust. Due to high reactivity, magnesium is not found in elemental form in the nature but only in chemical complexes, widely distributed in rock structures, seawater and lake brines. The inherent advantages of magnesium include a unique blend of low density, high specific strength, stiffness, electrical conductivity, heat dissipation and absorption of vibration. When combined with easy machining, casting, forming and recycling, magnesium is seen as a very attractive material for a large volume of applications. In recent years the interest in magnesium has grown dramatically, which has spurred academic research and industrial trials to identify more efficient ways of manufacturing the primary metal, as well as a search for new alloys and extending areas of their application.

General interest in structural applications of magnesium alloys is growing. For automotive applications, this has been largely due to an appealing set of properties including low density, high specific strength, acceptable ductility, and most importantly, low cost processing and assembly via die-cast components of intricate shape. Many studies have shown that alloying is a useful means of improving the performance of magnesium alloy, in which refining structures, solid solution strengthening and dispersion strengthening by addition of rare earth elements have been widely recognized. [1], [2] Lots of magnesium alloys belong to an aging alloy, so that heat treatment is also an effective way to improve the performance. If combining alloying and aging treatment properly, therefore, the performance of magnesium alloy could be more improved.

A number of technical issues pose barriers to expanding the wrought magnesium market. First and foremost are low production rates. A typical magnesium alloy must be extruded 5-10 times slower than a typical aluminum alloy. [3], [4] Recognizing this fact, researchers are investigating the causes and possible solutions. [5] One of the fundamental issues is that the temperature window where the material is workable, yet dose not suffer hot shortness (incipient melting), is quite narrow for the conventional extrusion alloys such as AZ61 and ZK60. [6] There has been some recent research examining alloys of lower alloying content in order to substantially increase production rates while maintaining sufficient strength.

Unalloyed magnesium, obtained from either the thermal or electrolytic route with different levels of purity, is not used for structural applications. For engineering applications, alloys are created that contain a number of different elements, including Al, Zn, Mn, Si, Zr, Ca, Ag, Li, Cu, alkaline or rare earth elements. The purpose of alloying additions is to improve strength and other properties of magnesium. Although alloying alters certain properties, the key features of magnesium-based alloys remain similar to those of pure magnesium.

Zinc improves room temperature strength through solid solution effect. [7] The solubility of zinc is 6.2% at 341°C and 2.8% at 204°C. Zinc also improves fluidity of the melt, but contents above 2% decrease elongation at fracture – especially in the solution-treated condition – and can cause cracking. The ductility reduction is explained through preferential segregation of Zn to the $Mg_{17}Al_{12}$ phase, thus increasing its volume fraction.

In the present study, to elucidate the effect of zinc addition, the microstructure and aging behaviors of Mg alloys containing 6 to 10wt.% Zn were investigated. After casting ingots, solid solution treatment at 330°C for 12 hrs was conducted on the ingots followed by aging at temperatures of 180 and 200°C for up to 48 hrs.

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II. Experimental Procedures

The materials used in this study were ingots of Mg alloys containing 6, 8, and 8wt. % zinc. Typical microstructure was given in Fig. 1. Phase equilibria of Mg-Zn alloy were calculated using FactSage®, a commercial thermodynamic simulation software, and FTLite database, from which conditions for solid solution treatment was taken as at 330°C for 12 hrs followed by water quenching. Aging treatment was carried out at 180°C and 200°C for up to 48 hrs. Microstructure evolution and variation of Vickers hardness after aging treatment were investigated in this study.

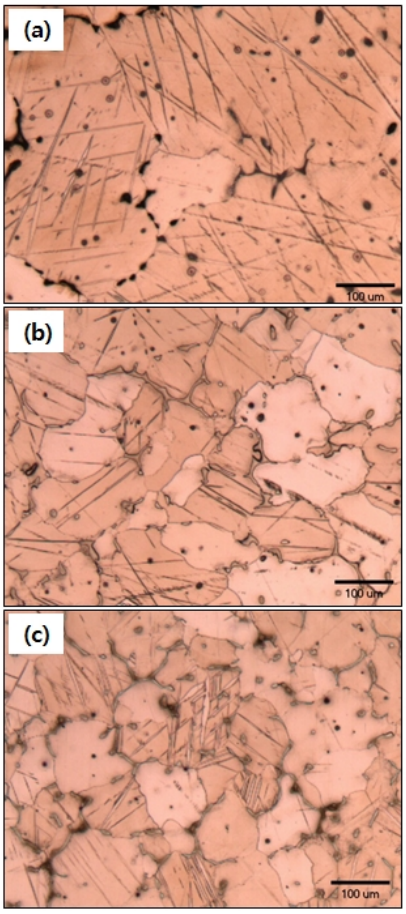

Fig. 1 Microstructure of as-cast Mg-Zn alloys containing various zinc contents of 6 (a), 8 (b), and 10 (c) weight percent respectively, used in this study

III. Results and Discussion

Fig. 1 shows microstructure of as-cast Mg-Zn alloys used in this study, revealing that a large amount of second phases, presumably considered to be $Mg_{12}Zn_{13}$ phase, as expected from the result of phase equilibria given in Fig. 2. Fig. 2 shows equilibrium phases and their weight fractions as a function of temperature calculated in this study. Liquid phase would disappear at 400°C on cooling and precipitation of $Mg_{12}Zn_{13}$ phase is expected from temperature of 300°C in Mg-6Zn alloy. With increasing Zn addition, as shown in Fig. 2 (b), another phase ($Mg_{61}Zn_{20}$) is expected to precipitate just after disappearance of liquid phase at 380°C. [8] It is obvious from these figures that supersaturated solid solution can be obtained by annealing the ingot at temperatures from 300 to 350°C without any liquid phase. However, in the case of Mg-8Zn and Mg 10Zn alloys, entirely supersaturated solid solution cannot be obtained within this temperature range. Using these results, solid solution treatment temperature was taken as 350°C to obtain supersaturated α solid solution.

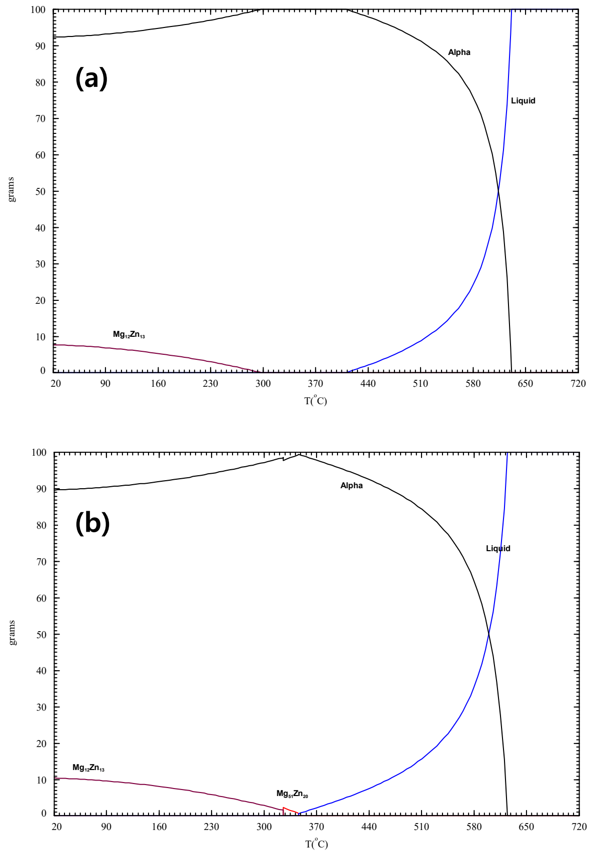

Fig. 2 Calculated phase equilibria of Mg-6Zn (a) and Mg-8Zn (b) alloys fabricated in this study

In Fig. 3, microstructure obtained after solution treatment followed by water quenching has been illustrated, in which almost all β-phases appeared to dissolve into matrix. Some precipitates still remained after solid solution treatment as expected from calculated phase equilibria given in Fig. 2.

Fig. 4 shows variation of hardness as a function of aging time obtained from aging treatment at 180 and 200°C. Hardness of Mg-Zn alloys was found to increase monotonically with aging time at 180°C, while, at 200°C, after increased until 10 hrs and reached maximum value, then hardness decreased with further aging treatment. Typical aging curve has been obtained at 200°C and peak aging conditions were deduced as 200°C for 10 hrs. Interestingly double peak in hardness of nonflammable alloy aged 200°C was observed, which should be more elucidated by further investigation. With aging time increased at 180°C, second phases precipitated along the grain boundaries and the amount appeared to increase monotonically. Similar result was obtained at aging treatment at 200°C. As shown in Fig. 5, with aging time increased, however, second phases were found to precipitate not only along the grain boundaries but also within the matrices and even lamellar structure could be observed after aging for 48 hrs. Interestingly, evidence for grain refinement can be observed in the specimen aged for 48 hrs.

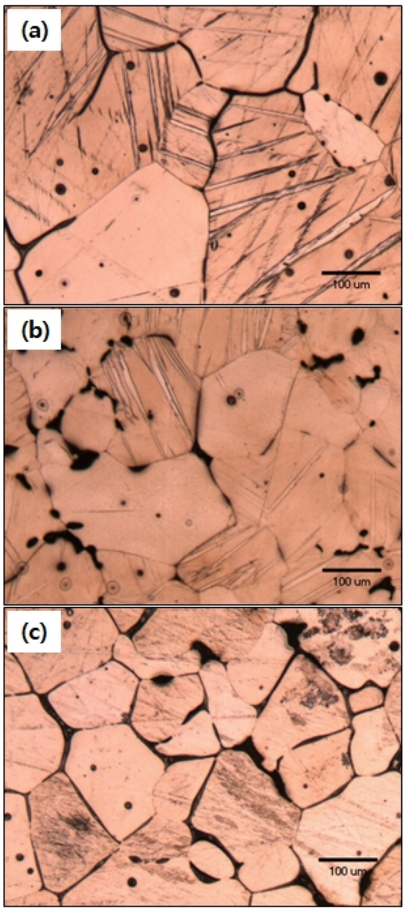

Fig. 3 Typical microstructure of Mg-Zn alloys containing various zinc contents of 6 (a), 8 (b), and 10 (c) weight percent, obtained after solid solution treatment followed by water quenching

It is well known that small amount of rare earth elements can exist in the intermetallic phases in the form of solid solution besides great amount of yttrium form intermetallic compounds [9]. Because the electronegativity difference between yttrium and aluminum is larger than that between magnesium and aluminum, there is a stronger chemical affinity between yttrium and aluminum. Thus yttrium in intermetallic phase would enhance the chemical stability of the second phase, and accordingly, would inhibit decomposition of the second phase during solution treatment, which is presumably attributed to somewhat lower hardness of magnesium alloys.

Figs. 7 and 8 show similar results observed in Mg-8Zn and Mg-10Zn alloys, in which a large amount of annealing twins together with slip bands can be observed. With increasing zinc contents, amount of precipitates formed during aging treatment apparently increased and grain refinement also occurred. It is explained by this feature that hardness of Mg-10Zn alloy increased monotonically during aging at 200°C up to 48 hrs.

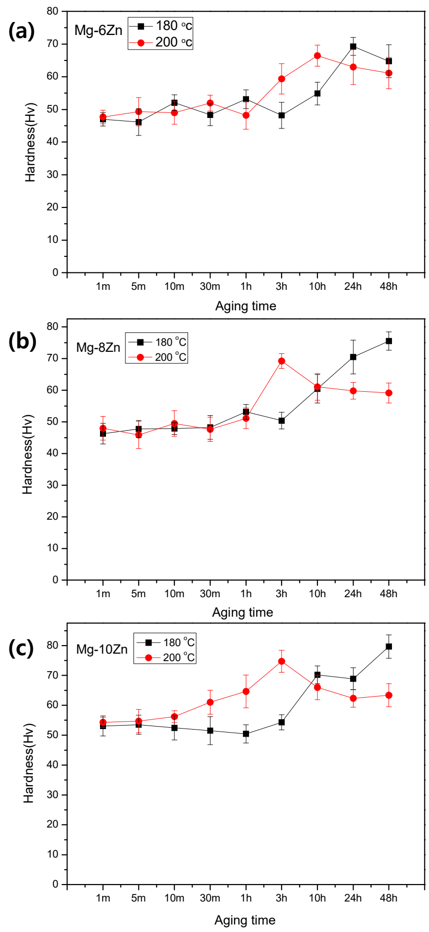

Fig. 4 Hardness of Mg-Zn alloys containing various zinc contents of 6 (a), 8 (b), and 10 (c) weight percent as a function of aging time obtained after aging treatment at 180 and 200°C

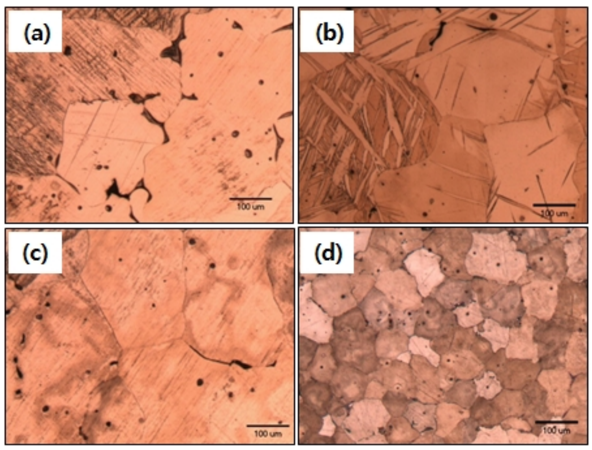

Fig. 5 Microstructure of Mg-6Zn alloy aged at 180°C for various times of 10 min (a), 1 hr (b), 10 hrs (c), and 48 hrs (d), respectively

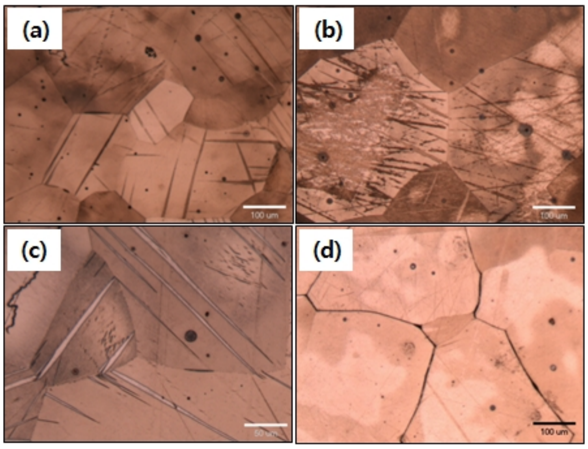

Fig. 6 Microstructure of Mg-6Zn alloy aged at 200°C for various times of 30 min (a), 1 hr (b), 10 hrs (c), and 48 hrs (d), respectively

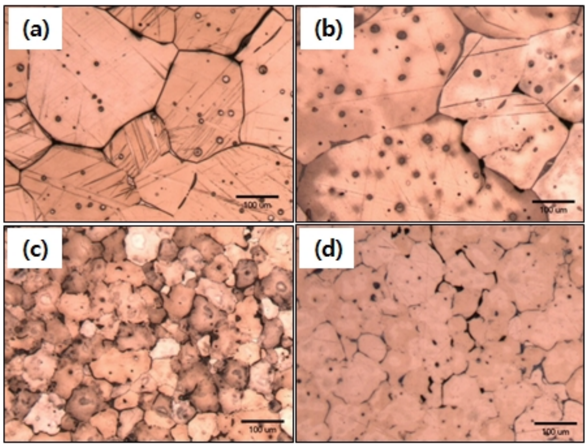

Fig. 7 Microstructure of Mg-8Zn alloy aged at 200°C for various times of 10 min (a), 1 hr (b), 10 hrs (c), and 48 hrs (d), respectively

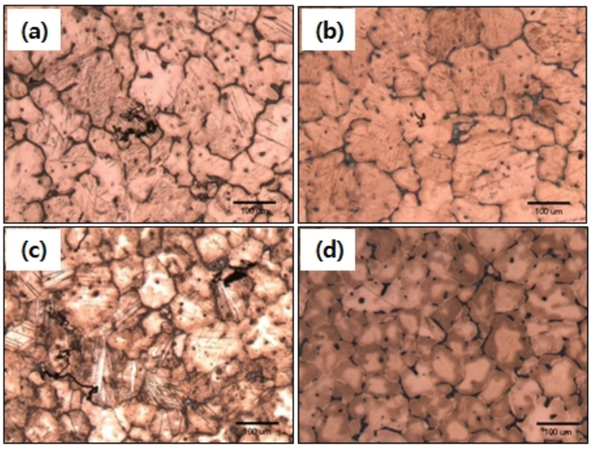

Fig. 8 Microstructure of Mg-10Zn alloy aged at 200°C for various times of 10 min (a), 1 hr (b), 10 hrs (c), and 48 hrs (d), respectively

IV. Conclusions

In the present study, aging behavior of Mg-Zn alloys containing 6-10 weight percent of Zn. Supersaturated solid solution can be obtained by annealing the ingot at temperatures from 300 to 350°C. Solid solution treatment conditions were deduced by solution treatment at 350°C for 12 hrs. Aging treatment was carried out at temperatures of 180 and 200°C for up to 48 hrs. Typical aging curve has been obtained at 200°C and peak aging conditions were deduced as 200°C for 3 hrs.

Acknowledgment

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