Magnesium Technology 2011

Alloy Design/Development; Grain Refinement and Severe Plastic Deformation

Session Chairs:

Matthew R. Barnett
(Deakin University, Australia)
Suveen N. Mathaudhu
(US Army Research Office, USA)

Magnesium Technology 2011
Edited by: Wim H. Sillekens, Sean R. Agnew, Neale R. Neelameggham, and Suveen N. Mathaudhu
TMS (The Minerals, Metals & Materials Society), 2011

EFFECT OF Zn/Gd RATIO ON PHASE CONSTITUTIONS IN Mg-Zn-Gd ALLOYS

S. Zhang[1,2], G.Y. Yuan[1,2], C. Lu[1,2], W.J. Ding[1,2]
[1]National Engineering Research Center of Light Alloy Net Forming, Shanghai Jiao Tong University, 800 Dongchuan Road, Shanghai 200240, PR China
[2]State Key Laboratory of Metal Matrix Composite, Shanghai Jiao Tong University, 800 Dongchuan Road, Shanghai 200240, PR China

Keywords: Mg-Zn-Gd alloys, long period stacking ordered (LPSO) structure, I phase

Abstract

This paper discusses the influence of Zn/Gd ratio on the phase constitutions of as-cast Mg-Zn-Gd alloys in the Mg-rich corner within the range of 0.5-3.0 at.% for Zn content and 0.5-3.0 at.% for Gd content. The critical Zn/Gd ratio for the formation of icosahedral quasicrystal phase (I phase) and long period stacking ordered (LPSO) structure in the Mg-Zn-Gd system has been confirmed. LPSO structure and $(Mg,Zn)_3Gd$ phase are formed in Mg-Zn-Gd alloys in the range of Zn/Gd ratio ≤ 1.0. However, only $(Mg,Zn)_3Gd$ phase is observed in the alloys in the range of $1.0 <$ Zn/Gd ratio < 1.5. And if Zn/Gd ratio is ≥ 1.5, I phase and $(Mg,Zn)_3Gd$ phase in the alloys begin to form gradually.

Introduction

The great interest in magnesium and its alloys as new light constructional materials for the applications in automobiles and aircrafts has led to numerous publications in this field. Recently, a lot of studies have been focused on Mg-Zn-Gd alloys reinforced by icosahedral quasicrystal phase (I-phase) [1-3], which show a good combination of strength and ductility because of the strong interface between I phase and α-Mg matrix [4]. In addition, Mg-Zn-Gd alloys with 14H-LPSO structure precipitate [5-8] have attracted increasing interest in the past years due to the high mechanical strength and good heat-resistance. Both I phase and LPSO structure are hopeful strengthening phases in Mg alloys, but the formation range of two phases in Mg-Zn-Gd systems are not clear yet. In this study, the critical Zn/Gd ratio for the formation of I phase and LPSO structure is investigated in Mg-Zn-Gd alloys in the Mg-rich corner by conventional cast process.

Experimental Procedure

Twenty Mg-Zn-Gd alloys in the range of 0.5-3.0 at.% for Zn content and 0.5-3.0 at.% for Gd content were prepared by melting the mixture of high purity Mg, Zn and Mg–25 wt.% Gd master alloys using high-frequency induction under protection of Ar gas, then cast into preheated mild steel mould with diameter size of 10mm for further investigations. The microstructure of the specimens was observed by an optical microscope (OM), a LEO1450 scanning electron microscope (SEM) and a JEOL-2010 transmission electron microscope (TEM) operating at 200kV. X-ray diffraction (XRD) measurements were performed for the phase analysis of all specimens.

Results and Discussion

All Mg-Zn-Gd specimens were divided into three groups, (a-c) the specimens in the range of Zn/Gd ratio ≤ 1.0, (d-f) the specimens in the range of $1.0 <$ Zn/Gd ratio < 1.5, and (g-i) the specimens in the range of Zn/Gd ratio ≥ 1.5. Figure 1 shows optical microstructures of as-cast Mg-Zn-Gd alloys. It is observed that the volume fraction of secondary phase increased with increasing content of Zn and Gd in the three groups, but their microstructures are similar.

As shown in Figure 1, fine lamellae are observed near grain boundaries in the specimens with Zn/Gd ratio ≤ 1.0. These lamellae precipitates are typically observed in as-cast Mg-Zn-Gd alloys with the content that Zn%<Gd% [5-8]. Wu et al. [7,8] firstly observed fine lamellae precipitates in the as-cast Mg-Zn-Gd alloy and confirmed it has a 14H-LPSO structure. In our study, to further confirm the existence of the LPSO structured lamellae, SEM and TEM observation was carried out for the Mg-1.5Zn-1.5Gd alloy.

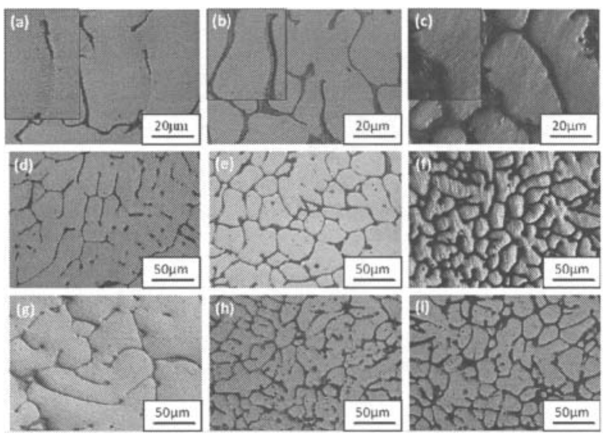

Figure1. Optical microstructures of (a) Mg-1.0Zn-1.0Gd, (b) Mg-1.5Zn-1.5Gd, (c) Mg-2.0Zn-2.0Gd, (d) Mg-1.2Zn-1.0Gd, (e) Mg-2.0Zn-1.5Gd, (f) Mg-2.5Zn-2.0Gd, (g)Mg-1.5Zn-1.0Gd, (h) Mg-2.5Zn-1.5Gd and (i) Mg-3.0Zn-2.0Gd alloys.

Figure 2 shows a typical SEM image and TEM graphs ($B//[110]_{\alpha\text{-}Mg}$) of fine lamellae in the Mg-1.5Zn-1.5Gd alloy. The selected area electron diffraction (SAED) pattern of fine lamellae shows that there exist 13 extra spots equally spaced between the central spot and the $(002)_{Mg}$ spots, implying that it has a 14H-type LPSO structure. It also can be observed that these lamellae have a specific relationship orientation with the matrix. The 14H-LPSO structured lamellae are formed along c*axle-[001] of the 2H-Mg. Zhu et al. [9,10] found that the stacking sequence of the 14H-LPSO structure in the Mg alloys is ABABCACACACBABA consisting of 2 ABCA stacking sequence structural units.

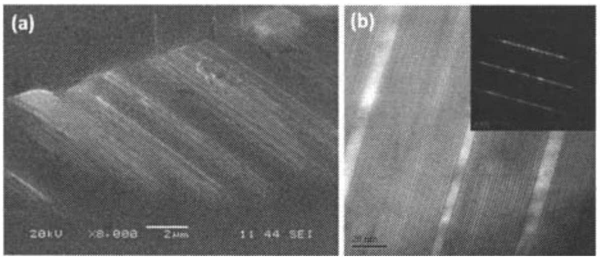

Figure 2. SEM (a) and TEM (b) images of fine lamellae in as-cast Mg-1.5Zn-1.5Gd alloy, the eclectic beam is parallel to [110]α-Mg.

Figure 3 shows XRD analysis of the specimens, which can prove the secondary phase in Mg-Zn-Gd alloys is $(Mg,Zn)_3Gd$ phase. Yamasaki et al. [6] firstly reported that the secondary phase in Mg-Zn-Gd alloy was a Mg_3Gd-type compound with a DO_3-type structure and lattice constant of a=0.720nm. In previous studies [2, 11] which focused on Mg-Zn-Gd alloys reinforced by I phase, $(Mg,Zn)_3Gd$ phase in Mg-Zn-Gd alloys was usually denoted as W phase. The peaks of $(Mg,Zn)_3Gd$ phase are observed a little deviation from the standard with increasing of Zn/Gd ratio. With the increasing of Zn/Gd ratio, the peaks of $(Mg,Zn)_3Gd$ phase deviate to high degrees a little, which means the lattice parameter of $(Mg,Zn)_3Gd$ phase is variable with the change of Zn/Gd ratio. The different lattice parameters of $(Mg,Zn)_3Gd$ phase in the three groups is calculated as a=0.710 (Zn/Gd ratio ≤1.0), a=0.701 (1.0< Zn/Gd ratio <1.5) and a=0.693 (Zn/Gd ratio ≥1.5). These results suggest that the lattice parameter of $(Mg,Zn)_3Gd$ phase is variable with the composition variety of Zn%-Gd% in the alloys.

As shown in Figure 3(a), only the peaks of α-Mg and $(Mg,Zn)_3Gd$ phase can be observed in the specimens with Zn/Gd ratio ≤1.0. But 14H-LPSO structure is not detected by XRD analysis because of their tiny volume fraction. Similarly, with the increasing of Zn/Gd ratio, only the peaks of α-Mg and $(Mg,Zn)_3Gd$ phase can be observed in the specimens with 1.0< Zn/Gd ratio <1.5, as shown in Figure 3b. In Figure 3c, the additional peaks in the specimens with Zn/Gd ratio ≥1.5 are identified to be I phase. Quasilattice parameter of I phase is calculated as a=0.520nm by using Elser's indexing method [12].

Figure 4 shows a typical SEM and TEM graphs of I phase in as-cast Mg-2.5Zn-1.5Gd alloy. The diffraction pattern reveals a 5-fold symmetry which is typical icosahedral quasicrystalline structure.

It has been reported [13] that the formation range of I phase in Mg-Zn-Gd system was about in the Zn/Gd ratio range of 1.5-40 in atomic percent. However, no researches appear concerning the relationship between the formation of LPSO structure and Zn/Gd ratio in Mg-Zn-Gd alloys, and whether or not there is a Mg-Zn-Gd alloy containing both I phase and LPSO structure. The formation range of I phase in Mg-Zn-Gd alloys in our studies is consistent with previous research. Furthermore, the formation range of LPSO structure in Mg-Zn-Gd alloy in the range of 0.5-3.0 at.% for Zn content and 0.5-3.0 at.% for Gd content is investigated, and expressed by Zn/Gd ratio. LPSO structured lamellae and I phase in the as-cast Mg-Zn-Gd alloys are formed in the range of Zn/Gd ratio ≤1.0 and Zn/Gd ratio ≥1.5, respectively. This provided a guide for the preparation and application of Mg-Zn-Gd alloys strengthening by LPSO structure or I phase. Zn/Gd ratio has to be chosen carefully with regard to the requirements of an application.

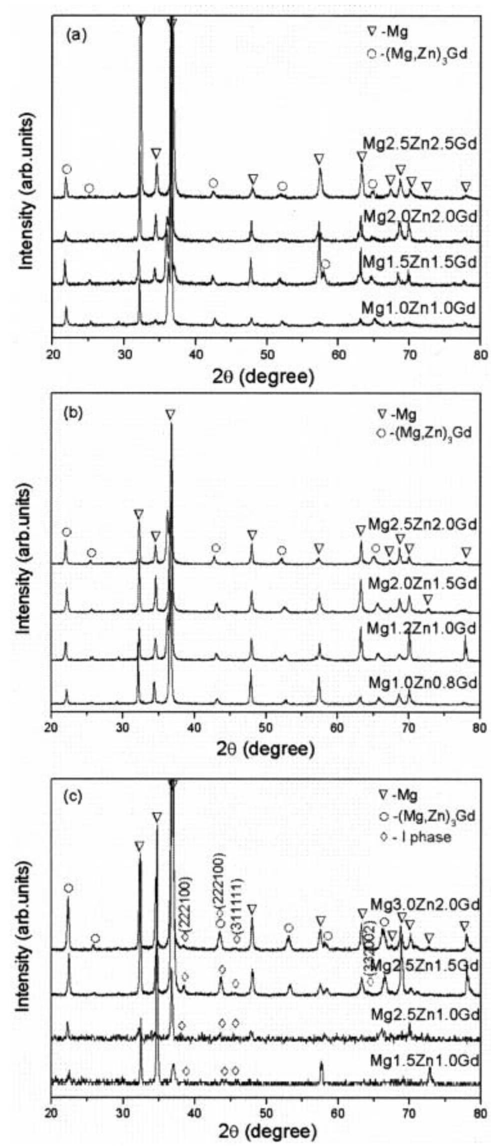

Figure 3. XRD analysis of (a) Mg-1.0Zn-1.0Gd, Mg-1.5Zn-1.5Gd, Mg-2.0Zn-2.0Gd and Mg-2.5Zn-2.5Gd alloys, (b) Mg-1.0Zn-0.8Gd, Mg-1.2Zn-1.0Gd, Mg-2.0Zn-1.5Gd and Mg-2.5Zn-2.0Gd alloys, (c) Mg-1.5Zn-1.0Gd, Mg-2.5Zn-1.0Gd, Mg-2.5Zn-1.5Gd and Mg-3.0Zn-2.0Gd alloys.

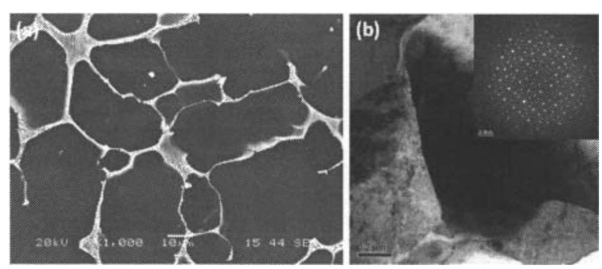

Figure 4. SEM image (a) and TEM images (b) of I-phase in Mg-2.5Zn-1.5Gd alloy, which exhibits 5-fold axe SAED pattern.

Summary

In this study, the formation range of I phase and LPSO structure in as-cast Mg-Zn-Gd alloys within the range of 0.5-3.0 at.% for Zn content and 0.5-3.0 at.% for Gd content was investigated by using XRD, OM, SEM and TEM. LPSO structure and $(Mg,Zn)_3Gd$ phase are formed in Mg-Zn-Gd alloys in the range of Zn/Gd ratio ≤ 1.0. However, there is only $(Mg,Zn)_3Gd$ phase observed in the alloys in the range of $1.0<$ Zn/Gd ratio <1.5. If Zn/Gd ratio is ≥ 1.5, I phase and $(Mg,Zn)_3Gd$ phase in the alloys began to form gradually. In general, the phase constitutions of Mg-Zn-Gd alloys under investigation are influenced by Zn/Gd ratio. These findings will be helpful to the alloy design to meet diverse requirements.

Acknowledgements

This work was supported by the National Nature Science Foundation of China (No.:50771063), and Science and Technology Commission of Shanghai Municipality (08JC1412200, 10JC1407400) and Jiangsu Key Laboratory of Advanced Metallic Materials (AMM200903). The help with the TEM observations received from the instrumental analysis center, Shanghai Jiao Tong University is also appreciated.

References

1. G.Y. Yuan, H. Kato, K. Amiya, A.Inoue, "Excellent creep properties of Mg-Zn-Cu-Gd-based alloy strengthened by quasicrystals and Laves phases," *Journal of Materials Research*, 20 (2005), 1278-1286.

2. G.Y. Yuan , Y. Liu , C. Lu, W.J. Ding, "Effect of quasicrystal and Laves phases on strength and ductility of as-extruded and heat treated Mg–Zn–Gd-based alloys," *Materials Science and Engineering A*, 472 (2008), 75-82.

3. Y. Liu, G.Y. Yuan, C. Lu, W.J. Ding, "Stable icosahedral phase in Mg-Zn-Gd alloy," *Scripta Materialia*, 55 (2006), 919-922.

4. A. Singh, H.Somekawa, T. Mukai, "Compressive strength and yield asymmetry in extruded Mg-Zn-Ho alloys containing quasicrystal phase," *Scripta Materialia*, 56 (2007), 935-938.

5. M. Yamasaki, T. Anan, S. Yoshimoto, Y. Kawamura, "Mechanical properties of warm-extruded Mg–Zn–Gd alloy with coherent 14H long periodic stacking ordered structure precipitate," *Scripta Materialia*, 53 (2005), 799–803.

6. M. Yamasaki, M. Sasaki, M. Nishijima, K. Hiraga, Y. Kawamura, "Formation of 14H long period stacking ordered structure and profuse stacking faults in Mg-Zn-Gd alloys during isothermal aging at high temperature," *Acta Materialia*, 55 (2007), 6798-6805.

7. Y.J.Wu, X.Q. Zeng, D.L. Lin, L.M. Peng, W.J. Ding, "The microstructure evolution with lamellar 14H-type LPSO structure in an Mg96.5Gd2.5Zn1 alloy during solid solution heat treatment at 773 K," *Journal of Alloys and Compounds*, 477 (2009), 193-197.

8. Y.J.Wu, D.L. Lin, X.Q. Zeng, L.M. Peng, W.J. Ding, "Formation of a lamellar 14H-type long period stacking ordered structure in an as-cast Mg–Gd–Zn–Zr alloy," *Journal of Materials Science*, 44 (2009), 1607-1612.

9. Y.M. Zhu, A.J. Morton, J.F. Nie, "The 18R and 14H long-period stacking ordered structures in Mg-Y-Zn alloys," *Acta Materialia*, 58 (2010), 2936-2947.

10. Y.M. Zhu, M. Weyland, A.J. Morton, K. Oh-ishi, K. Honod, J.F. Nie, "The building block of long-period structures in Mg-RE-Zn alloys," *Scripta Materialia*, 60 (2009), 980-983.

11. Z.P. Luo, H. Hashimoto, "High-resolution electron microscopy observation of a new crystalline approximant W' of Mg–Zn–Y icosahedral quasicrystal," *Micron*, 31 (2000), 487-492.

12. V.Elser, C.L. Henley, "Crystal and quasicrystal structures in Al-Mn-Si alloys," *Physical Review Letters*, 55 (1985), 2883-2886.

13. Y. Liu, G.Y. Yuan, S. Zhang, X.P. Zhang, C. Lu, W.J. Ding, "Formation range of Icosahedral phase of Mg-Zn-Gd system in the Mg-rich section," *Materials Transactions*, 49 (2008), 941-944.