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Characterization of phases in Mg-10Y-5Gd-2Zn-0.5Zr alloy processed by heat treatment

WANG Qu-dong(王渠东)[1], GAO Yan(高 岩)[1, 2], YIN Dong-di(尹冬弟)[1], CHEN Chang-jiang(陈长江)[1]

1. National Engineering Research Center of Light Alloys Net Forming, Shanghai Jiao Tong University, Shanghai 200240, China;
2. Grikin Advanced Materials Co., Ltd, Beijing General Research Institute of None-ferrous Metals, Beijing 100220, China

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Abstract: Characterizations of phases in Mg-10%Y-5%Gd-2%Zn-0.5%Zr (WGZ1052) alloy during heat treatments were investigated by OM, XRD, SEM and EDS. The mechanisms of microstructure evolution were discussed. The results show that, after high temperature heat treatments, the $Mg_{12}ZnY$ phases still exist. During solution-treatment at 535 °C, the amount of the long-period stacking order structures decreases. At 545 °C for 20 h and 24 h, there are still remnant $Mg_{12}ZnY$ compounds in the Mg matrix, the shape of which does not change and the amount does not decrease obviously.

Key words: Mg-Y-Gd-Zn alloy; long-period stacking order; heat treatment

1 Introduction

Mg-base alloys with rare-earth elements are becoming more and more attractive due to their high strength and creep resistance[1−2]. Mg-Gd-Y-Zr alloys were developed with higher specific strength at both room and elevated temperatures and higher creep resistance than WE54 and QE22[3−5].

On the other hand, the addition of Zn or Cu can further improve the strengthening response of Mg-RE alloys. $Mg_{97}Zn_1Y_2$ (molar fraction, %) was developed using rapidly solidified powder metallurgy in 2001[6]. It is a novel alloy with superior mechanical properties including tensile yield strength of 610 MPa and elongation of 5%. In 2003, AMIYA[7] and MATSUURA et al[8] subsequently reported that the Y and Zn elements were enriched in the long-period region and the periodicity changed from 6H-type to 14H-type with increasing cooling rate in melt spinning $Mg_{97}Zn_1Y_2$. In 2004, ITOI et al[9] reported that a long-period stacking order (LPSO) structure with 18R-type was observed in $Mg_{97}Zn_1Y_2$ alloy prepared by Cu-mould casting and induction melting methods. It is very interesting that such small additives like 1%−2% (molar fraction) Zn and Y into pure Mg dramatically change its microstructure and mechanical properties.

All these methods need highly non-equilibrium synthesis in a thermo-dynamically unstable state. So, industrial applications of the new materials are often limited. It was reported that Mg-10%Y-5%Gd-2%Zn-0.5%Zr (mass fraction) alloy with novel long-period ordered structure was processed via a conventional casting method[10]. The cast alloy showed excellent high temperature strength and creep resistance at 200−300 °C[11], indicating it was a very promising casting creep-resistant Mg alloy for high temperature applications[12−17]. Furthermore, this alloy has successfully been used as manufacturing engine piston by CHEN et al[18]. However, very little is known about the characterizations of phases in the alloy. A better understanding is very important from both the scientific and engineering points of view. In this work, the evolutions of microstructure and LPSO structure were investigated and the formation mechanism was discussed.

2 Experimental

Alloys with actual composition of Mg-10.3Y-

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Corresponding author: WANG Qu-dong; Tel: +86-21-54742715; Fax: +86-21-34202794; E-mail: wangqudong@sjtu.edu.cn
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5.6Gd-2.0Zn-0.5Zr (mass fraction, %) (WGZ1052) were prepared from high purity (≥99.9%) Mg, Zn and Mg-25Y (mass fraction, %), Mg-25Gd (mass fraction, %) and Mg-30Zr (mass fraction, %) master alloys by induction melting in a mild steel crucible at approximate 750 °C under a mixed atmosphere of CO_2 and SF_6 with the volume ratio of 100:1. Then, the alloy was cast into a steel mould and pre-heated to 200 °C. As-cast specimens of WGZ1052 alloy were solution treated at 535−545 °C for 16−24 h and then quenched into cold water. The constituent phases were identified by X-ray diffraction (XRD) with Cu K_α radiation. The microstructures of specimens were analyzed by optical microscope (OM) and scanning electron microscope (SEM) equipped with an energy dispersive X-ray spectrometer (EDS).

3 Results and discussion

Optical microstructure of the conventional casting WGZ1052 alloy is shown in Fig.1. The phase composition of the alloy obtained by XRD analysis is shown in Fig.2. Fig.3 and Table 1 show SEM images of WGZ1052 alloy and its corresponding EDX analysis results, respectively. It is found that WGZ1052 alloy mainly consists of four phases, matrix of primary α-Mg solid solution supersaturated with Gd, Y and Zn (Point A in Fig.3); network-shaped eutectic compound $Mg_{24}(GdYZn)_5$ (Point B in Fig.3); network-shaped compound $Mg_{12}YZn$ (Point C in Fig.3) and fine-lamellar phases (Point D Fig.3). The magnified images of fine-lamellar phases are shown in Fig.3(b). Most $Mg_{24}(GdYZn)_5$ compounds are distributed at the grain boundaries. The fine-lamellar phase uniformly distributes from eutectic compounds to the inner of α-Mg grains. These phases have specific orientation in the matrix grains and only one orientation in one grain (Fig.3(b)), which suggests that the fine-lamellar phases have specific orientation relationship with the α-Mg matrix crystals.

The temperature of solution heat treatment was determined on the basis of Mg-Gd and Mg-Y phase diagrams, and DSC curves[4−5, 11]. The microstructure evolutions at different solution temperature and time are shown in Fig.4. It is found that at 535 °C, the $Mg_{24}(GdYZn)_5$ net-work of second phase is completely dissolved after heated for 16 h (Fig.4(a)), but the black network-shaped compound $Mg_{12}YZn$ still survives in the matrix.

There are still remnant $Mg_{12}YZn$ compounds in the matrix at 545 °C for 20 h and 24 h, the shape of which does not change and the amount does not decrease

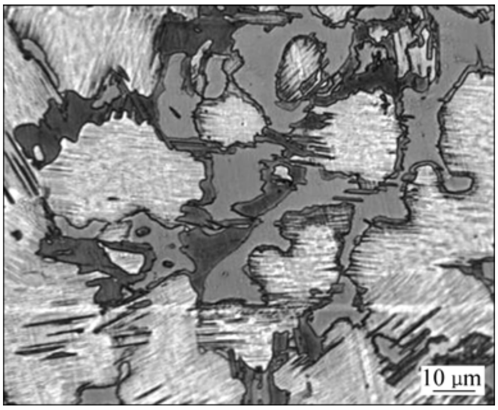

Fig.1 Optical microstructure of as-cast WGZ1052 alloy

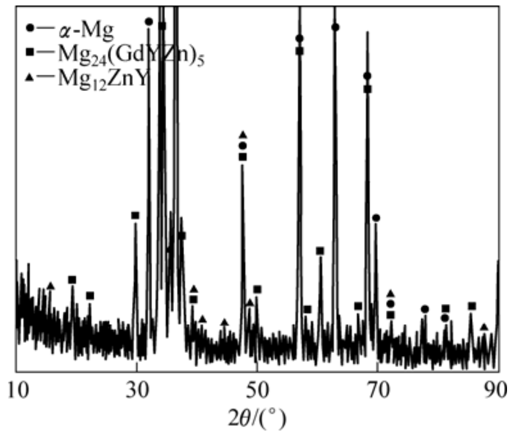

Fig.2 XRD pattern of as-cast WGZ1052 alloy

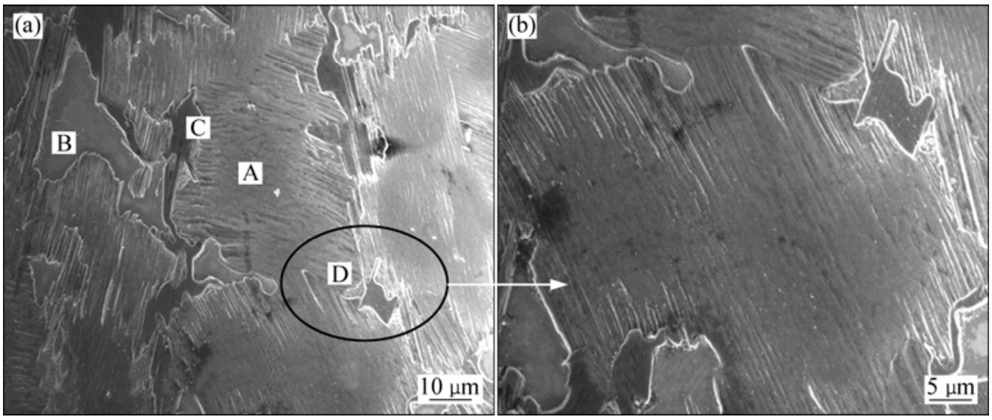

Fig.3 SEM images of WGZ1052 alloy

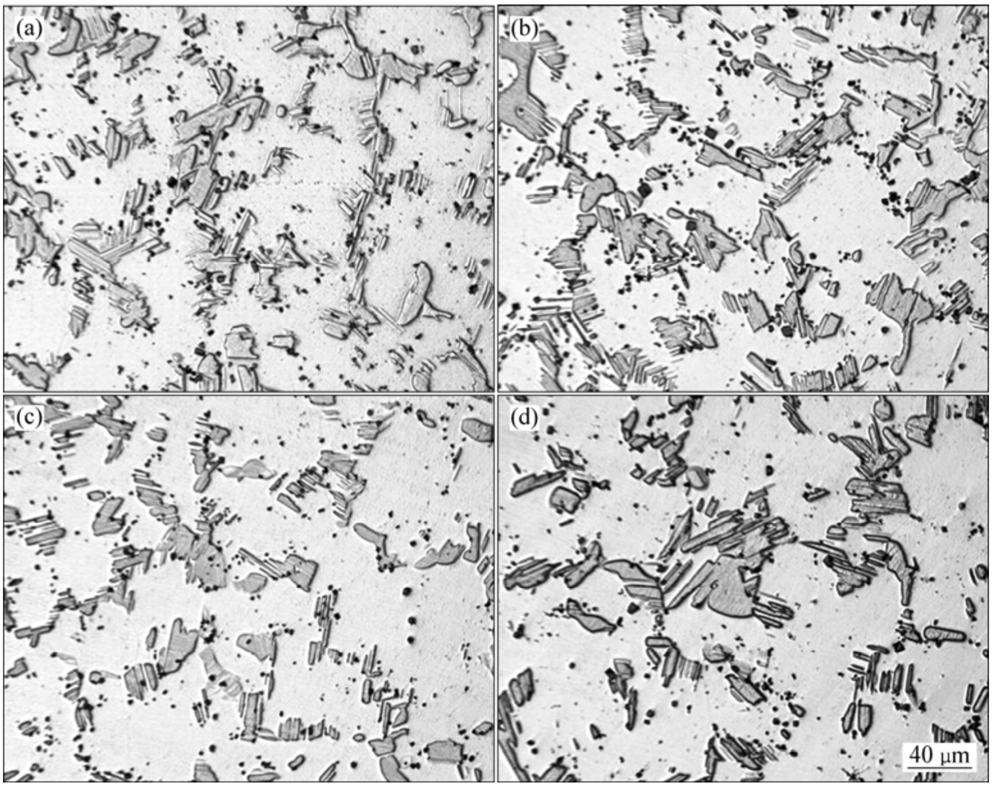

Fig.4 Microstructures of WGZ1052 alloys with different treatment: (a) 535 °C, 16 h; (b) 535 °C, 20 h; (c) 545 °C, 20 h; (d) 545 °C, 24 h

Table 1 EDX analysis results of as-cast WGZ1052 alloy in Fig.3 (molar fraction, %)

Element	Point A	Point B	Point C	Point D
Mg	96.91	92.42	85.39	96.22
Y	2.17	4.53	9.75	2.78
Gd	0.53	1.28	0.07	0.13
Zn	0.39	1.76	4.79	0.87

obviously. It can be concluded that the $Mg_{12}YZn$ is a high temperature stable phase and does not dissolve into the magnesium matrix at high temperatures.

The XRD pattern of the WGZ1052 alloy solution heat treated at 535 °C for 16 h is shown in Fig.5, which indicates that T4-WGZ1052 alloy mainly consists of α-Mg solid solution and $Mg_{12}YZn$ compounds.

Fig.6 shows the SEM image of the solution treated sample and corresponding EDX analysis results, which indicates that all the network-shaped eutectic compound $Mg_{24}(GdYZn)_5$ are dissolved in the matrix (Point A). It can be seen that the contents of Zn and Y elements at point B are high. The EDS analysis shows that the average molar ratio of Zn to Y is equal to 1:1, which indicates the stoichiometry of the compound is $Mg_{12}YZn$.

At elevated temperature, the grain-boundary softens and grain-boundary sliding becomes another possible deformation mechanism[19]. The denser $Mg_{12}YZn$ phases distributing along the grain boundary which have a good thermal stability and greater strength than the grains of solid-solutionized HCP-Mg[20], can pin the grain-boundary sliding and strengthen the boundaries effectively. So, this $Mg_{12}YZn$ phase may play an important role in strengthening the present WGZ1052 alloy because it acts as an effective second hard phase dispersed in the matrix. But the exact role of $Mg_{12}YZn$ phase in strengthening has not been clarified yet. Now, the high temperature strength and creep properties of the WGZ1052 alloy are being studied, and the systematic results will report the relation of intensity, $Mg_{12}YZn$ formation and the interactive effect of dislocation structure and $Mg_{12}YZn$ phase.

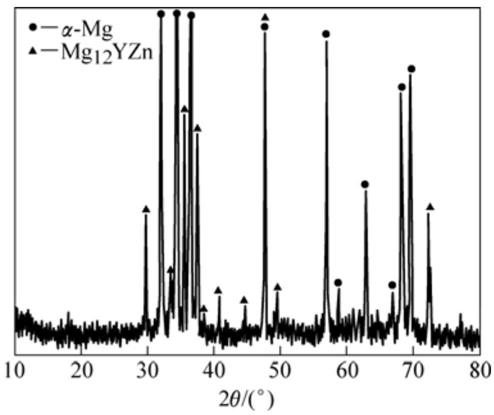

Fig.5 XRD pattern of WGZ1052 specimen solution treated at 535 °C for 16 h

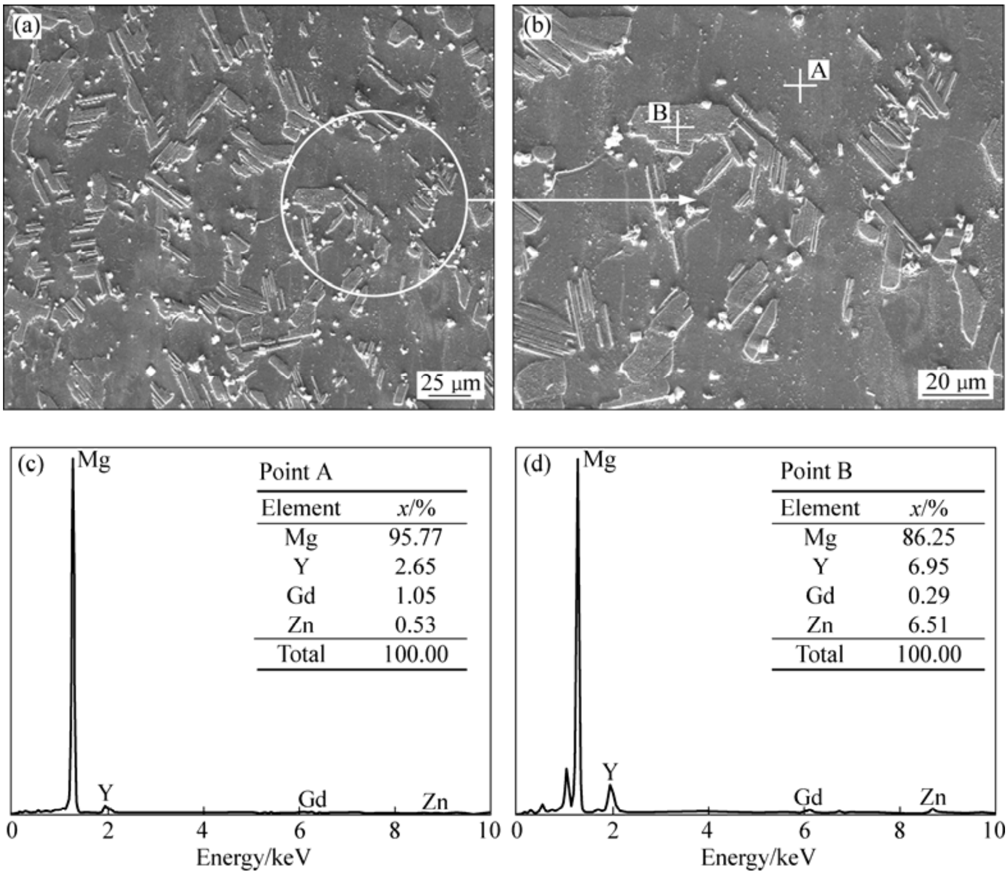

Fig.6 SEM images (a, b) and EDS patterns (c, d) of solution treated WGZ1052 alloy

4 Conclusions

1) The conventionally casting WGZ1052 alloy mainly consists of matrix of primary α-Mg solid solution supersaturated with Gd, Y and Zn, network-shaped eutectic compound $Mg_{24}(GdYZn)_5$, network-shaped compound $Mg_{12}YZn$ and fine-lamellar phases.

2) For 16 h solution treatment at 535 °C, the net-work second phase $Mg_{24}(GdYZn)_5$ completely dissolves, but the black network-shaped compound $Mg_{12}YZn$ still survives in the matrix.

3) There are still remnant $Mg_{12}YZn$ compounds in the matrix at 545 °C for 20 h and 24 h, the shape of which do not change and the amount does not decrease obviously. It can be concluded that the $Mg_{12}YZn$ is a high temperature stable phase and does not dissolve into the magnesium matrix at high temperatures.

References

[1] LI Da-quan, WANG Qu-dong, DING Wen-jiang. Effects of heat treatments on microstructure and mechanical properties of Mg-4Y-4Sm-0.5Zr alloy [J]. Materials Science and Engineering A, 2007, 448(1/2): 165−170.

[2] MORDIKE B L. Development of highly creep resistant magnesium alloys [J]. Journal of Materials Processing Technology, 2001, 117(3): 391−394.

[3] ROKHLIN L L. Advanced magnesium alloys with rare-earth metal additions: Advanced light alloys and composites [C]//CIACH R. Conference of the NATO advanced study institute on advanced light alloys and composites. Poland: Springer, 1998: 443−447.

[4] ANYANWU I A, KAMADO S, KOJIMA Y. Aging characteristics and high temperature tensile properties of Mg-Gd-Y-Zr alloys [J]. Materials Transactions, 2001, 42(7): 1206−1211.

[5] HE S M, ZENG X Q, PENG L M, GAO X, NIE J F, DING W J. Microstructure and strengthening mechanism of high strength Mg-10Gd-2Y-0.5Zr alloy [J]. Journal of Alloys and Compounds, 2007, 427(1/2): 316−323.

[6] KAWAMURA Y H K I. Rapidly solidified powder metallurgy $Mg_{97}Zn_1Y_2$ alloys with excellent tensile yield strength above 600 MPa [J]. Materials Transactions, 2001, 42(7): 1172−1176.

[7] AMIYA K A O T. Long-period hexagonal structures in melt-spun $Mg_{97}Ln_2Zn_1$ (Ln=Lanthanide metal) alloys [J]. Materials Transactions, 2003, 44(10): 2151−2156.

[8] MATSUURA M, SAKURAI M, AMIYA K, INOUE A. Local structures around Zn and Y in the melt-quenched Mg97Zn1Y2 ribbon [J]. Journal of Alloys and Compounds, 2003, 353(1/2): 240−245.

[9] ITOI T, SEIMIYA T, KAWAMURA Y, HIROHASHI M. Long period stacking structures observed in Mg97Zn1Y2 alloy [J]. Scripta Materialia, 2004, 51(2): 107−111.

[10] GAO Y, WANG Q D, GU J H, ZHAO Y, TONG Y, YIN D D. Comparison of microstructure in Mg-10Y-5Gd-0.5Zr and Mg-10Y-5Gd-2Zn-0.5Zr alloys by conventional casting [J]. Journal of Alloys and Compounds, 2009, 477(1/2): 374−378.

[11] CHEN Chang-jiang, WANG Qu-dong, YIN Dong-di, DING Wen-jiang. Microstructure and mechanical properties of

Mg-11Y-5Gd-2Zn-0.5Zr(wt.%) alloy [J]. Journal of Materials Science and Engineering, 2009, 27(6): 829−833. (in Chinese)

[12] CHEN Chang-jiang, WANG Qu-dong, YIN Dong-di, DING Wen-jiang. Research process in piston materials of combustion engine [J]. Materials Review, 2009, 23(15): 62−65. (in Chinese)

[13] LUO A A. Recent magnesium alloy development for elevated temperature applications [J]. International Materials Reviews, 2004, 49(1): 13−30.

[14] GUO Guo-qing, XIE Jing-pei, WANG Jie-fang, WANG Wen-yan, WANG Ai-qin, LI Luo-li. Piston materials and related technology [J]. Tractor & Farm Transporter, 2004, 3: 9−11. (in Chinese)

[15] PEKGULERYUZ M O, KAYA A A. Creep resistant magnesium alloys for powertrain applications [J]. Advanced Engineering Materials, 2003, 5(12): 866−878.

[16] AGHION E, BRONFIN B, von BUCH F, SCHUMANN S, FRIEDRICH H. Newly developed magnesium alloys for powertrain applications [J]. JOM, 2003, 55(11): 30−33.

[17] LUO A A. Magnesium: current and potential automotive applications [J]. JOM, 2002, 54(2): 42−48.

[18] CHEN Chang-jiang, WANG Qu-dong, HU Zhi-heng, YIN Dong-di, DING Wen-jiang. Simulation of heat-resistant magnesium alloy piston casting process [J]. Special Casting & Nonferrous Alloys, 2010, 30(6): 517−519. (in Chinese)

[19] DIETER G E. Mechanical metallurgy 3rd ed [M]. New York: McGraw-Hill, 1986: 751.

[20] MATSUDA M, LI S, KAWAMURA Y, IKUHARA Y, NISHIDA M. Interaction between long period stacking order phase and deformation twin in rapidly solidified Mg97Zn1Y2 alloy [J]. Materials Science and Engineering A, 2004, 386(1/2): 447−452.

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