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Aging characteristics and high temperature properties of Mg-9Gd-3Y-0.3Zr

YAO Su-juan(姚素娟)[1,2], YI Dan-qing(易丹青)[1], YANG Sheng(杨　胜)[1], LI Wang-xing(李旺兴)[2]

1. School of Materials Science and Engineering, Central South University, Changsha 410083, China;
2. Zhengzhou Research Institute of CHALCO, Zhengzhou 450041, China

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Abstract: The microstructures and tensile properties of Mg-9Gd-3Y-0.3Zr alloys were investigated by OM, SEM and mechanical property tester. The results show that the microstructure of as-cast sample is a typical dendritic structure, the grain size of extruded sample is finer than that of the as-cast because of recrystallization. The aging response of extruded specimens is quick and marked when the samples are aged at 200 to 250 ℃ for different time, and the peak aging hardness is about HV120. The tensile strengths at 25, 200, 250 and 300 ℃ are 375, 364, 329 and 286 MPa, respectively. The maximum elongation is higher than 18% at 300 ℃. The fracture mode is mainly microvoid coalescence fracture combining with brittle cleavage fracture at room temperature, and microvoid coalescence fracture at 250−300 ℃.

Key words: magnesium alloy; rare earth; aging treatment; tensile property

1 Introduction

Magnesium alloys are used to an increasing extent in applications where the components are subjected to high temperature. But the disadvantage of poor properties at elevated temperature is a barrier for the alloys application[1−2]. The problem is often solved by new production methods, with addition of alloying elements or other methods. Rare earth is added to magnesium alloys to improve their elevated temperature properties[2−4]. The start point is the traditional alloys containing RE series (WE54, WE43) which show excellent elevated temperature properties[5]. In recent years, much research work has been reported that Mg-Gd-Y-Zr alloy exhibits higher tensile properties superior to WE series alloys at elevated temperature [6−10]. However, most of those research works focus on alloys containing high zirconium[11−12]. The properties of alloys containing low zirconium have not been reported or less reported, the effects of low zirconium to the properties of Mg-Gd-Y-Zr alloys are not clearly known. So it is necessary to study the alloys to determine the heat treatment and the properties of those alloys.

Therefore, in this research, the influence of heat treatment on the microstructure and the property of Mg-9Gd-3Y-0.3Zr were investigated. The aim is to evaluate the suitable heat treatment for the alloy and the high temperature performance of the alloy.

2 Experimental

The alloy was prepared in an electric resistance furnace under the protection of flux and argon atmosphere, the flux made in lab was different from RJ series. the elements of Gd, Y, Zr were added in melted magnesium at 800−830 ℃ in form of Mg-Gd, Mg-Y, Mg-Zr master alloys. After melting, stirring and killing for about 15 min, the melt was poured into a graphite mold heated to 200−250 ℃ and then quenched quickly by cold water. The chemical compositions of investigated alloy ingots are listed in Table 1.

The homogenization of the alloy ingots used for extruding was carried out at 500 ℃ for 6 h, this treatment results in the decreasing residual intermetallic compounds in the alloys. The extrusion was carried out at 440−460 ℃ and extrusion rate about 2 m/min. The specimens of extrusion were directly aged at 200−250 ℃. The hardness of the samples was measured using a HVS−5 Vickers hardness tester in order to obtain aging characteristics curve of the investigated alloy and analyze the precipitates contribution to age hardening.

Corresponding author: YAO Su-juan; Tel: +86-411-68918695; E-mail: csuyaosuj@yahoo.com.cn

The microstructures of the samples were observed with Leica optical microscope. The TECNAI G2 20 was used to investigate the precipitation phase. The tensile properties of peak-aged samples were evaluated with Italy sun 10 tensile tester from room temperature to 300 ℃ at an rate extension of 2 mm/min.

Table 1 Chemical compositions of investigated alloy(mass fraction, %)

Element	Nominal composition	Analysis composition
Gd	9	9.24
Y	3	2.83
Zr	0.3	0.28
Mg	Bal.	Bal.

3 Results and discussion

3.1 Phase structure of alloys

Fig.1 shows the microstructures of investigated alloys in as-cast, cast-T4 and extruded-T5 conditions. The microstructures of the as-cast ingots are almost polylateral equiaxed crystal, the inner grain is a typical dendritic structure, the size of dendrite and dendritic distance are very small, and the grain size is about 40−60 μm. There are pronounced second segregation particles distributing in grains and at grain boundaries. Fig.1 (b) indicates that all dendrites existing in grains totally disappear after specimen have been treated at 500 ℃ for 6 h. Lots of twins are present in some grains, the second-phase particles formed during solidification were dissolved at 500 ℃, and the remains in grains and at grain boundaries decrease, But still some particles distribute throughout the microstructure. This phenomenon can be explained that these particles containing rare-earth have high temperature stability. The grain size after solution treatment(Fig.1(b)) does not become larger compared with the as-cast specimen (Fig.1(a)), but the grain boundaries become straighter, the structure turns to a typical equiaxed crystal. The microstructure of the extruded specimen is very fine, most second -particles distribute in the streamlines parallel to the extruding direction, which indicates that the specimens undergo strong plastic deformation during extruding, and it is obvious that the dynamic recrystallization occurs in the specimens during extruding and subsequent cooling process. The grains of extruded specimen with size of 10−30 μm are much finer than those of the as-cast and cast-T4 specimens.

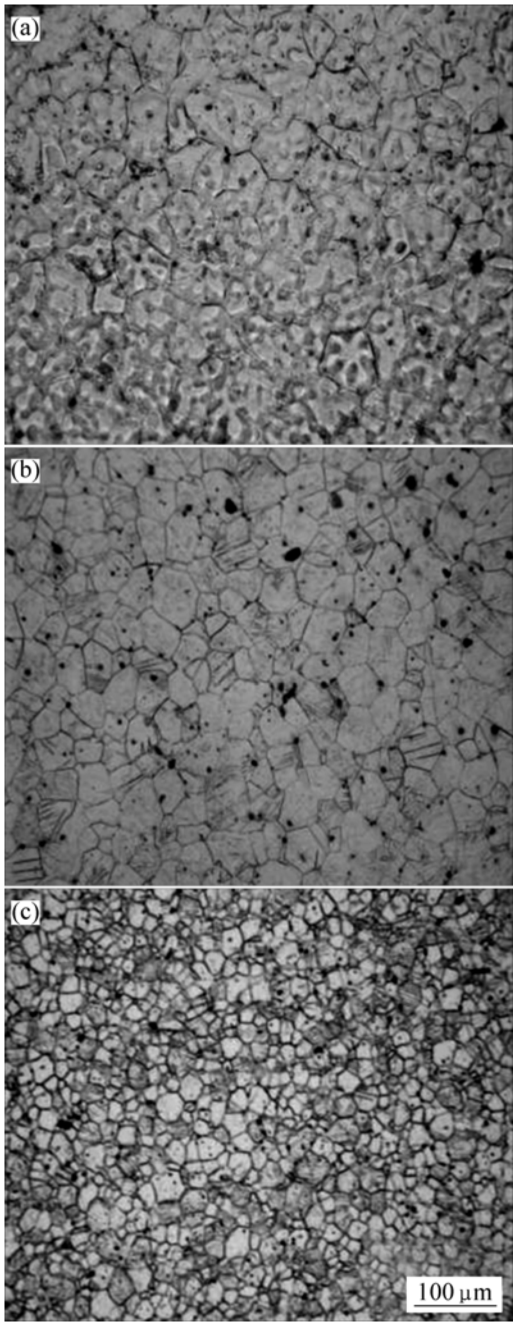

Fig.1 Microstructures of investigated alloys in as-cast**,** cast-T4 and extruded-T5 conditions: (a) As-cast; (b) Cast-T4 (500 ℃, 6 h); (c) Extruded-T5 (225 ℃, 24 h)

3.2 Aging kinetics of extruded specimens

The investigated alloy is one of the magnesium alloy series that can be hardened by aging treatment. The isothermal aging tests were taken to evaluate the response of alloy to precipitation hardening during aging treatment. The results were measured by changing hardness. Fig.2 shows the aging kinetics of the investigated alloys at 200, 225 and 250 ℃. The aging response of investigated alloy is quick and marked. A small difference of aging response was observed at three ageing temperatures, the peak aging hardness at 200 ℃ is the highest, but the time to peak-aging is the longest, the aging curve at 250 ℃ indicates that the effectiveness at 250 ℃ is not as good as that at 200 and 225 ℃.

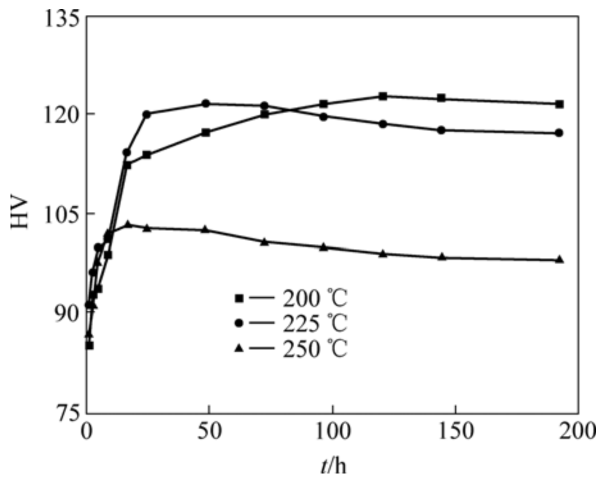

Fig.2 Aging kinetics of investigated alloy at different temperatures

Fig.3 shows the microstructure of specimen observed along the $[0001]_{\alpha}$ orientation in peak-aging condition. There are two species of precipitates, one is thin platelet the other is spheroidal particle. The thin platelet phase is β' with $D0_{19}$ structure[13], the spheroidal particle phase was identified by NIE et al[14] in WE54 is β'. IFEANYI-ANTHONY et al[15] concluded that in the peak aged Mg-Gd-Y-Zr alloys, β'' and β' phases coexist and both precipitates contribute to age hardening and be responsible for the peak mechanical and creep properties at high temperature.

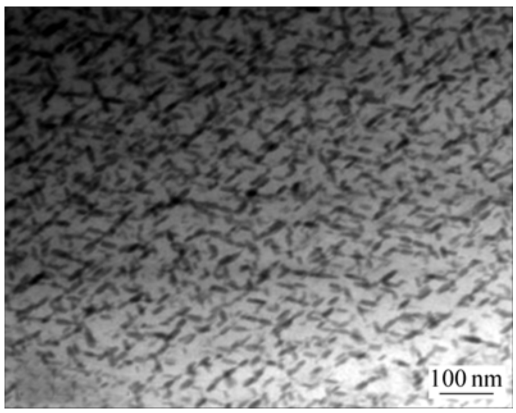

Fig.3 Bright field micrograph of extruded sample aged at 225 ℃ for 24 h

3.3 Tensile properties of extruded specimens

Fig.4 shows the tensile strength and elongation of the investigated extruded alloys-T5. The curve indicates a tend that the tensile strength of the alloy decreases and the elongation increases with the temperature rising, the tensile strength declines slowly from room temperature to 200 ℃, but when the temperature is higher than 200 ℃, it reduces sharply. IFEANYI-ANTHONY et al[15] believe that this phenomenon is due to the transformation of β'' and β' precipitates into equilibrium phase and the subsequent coarsening of the precipitates with rising temperature.

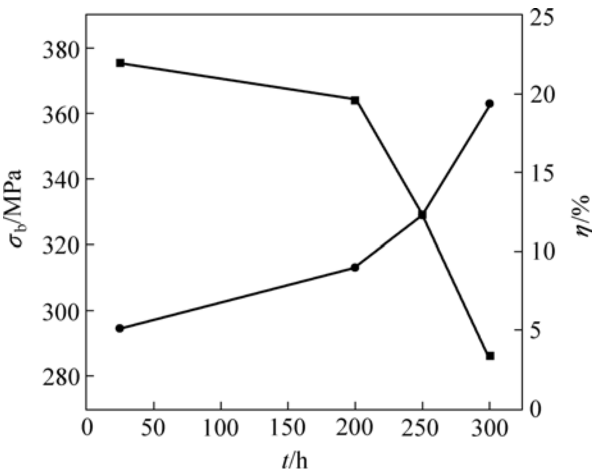

Fig.4 Tensile strength and elongation as a function of temperature

The authors believe that the grain deformation also contributes to this change except precipitates coarsening. Some information from Fig.5 can prove it. The grains almost do not change at room temperature, but the deformation degree of grains along tensile direction becomes more and more marked with the temperature rising.

In the optical micrographs shown in Figs.5(a)−(d), it can be seen that many particles distribute in the grains and at grain boundaries, and many deformation twins keep about 45° angle with the tensile direction, cavities originate at the boundaries during tensile deforming at each temperature by stress concentration, and with the increasing of deformation, more cavities appear and propagate along the grain boundaries which are almost vertical to the tensile direction. Some cracks expand into the grains. The fracture surfaces in Figs.5(e)−(h) shows that the fracture mode at room temperature is microvoid coalescence fracture and brittle cleavage fracture. There are a number of dimples and white tear ridges on the fracture surfaces of samples tested at 200 ℃, 250 ℃ and 300 ℃(Figs.5(f)−(h)), and many second particles in the dimples. These indicate some microcracks initiate at the interfaces of particles /Mg and contribute to the failure of specimens.

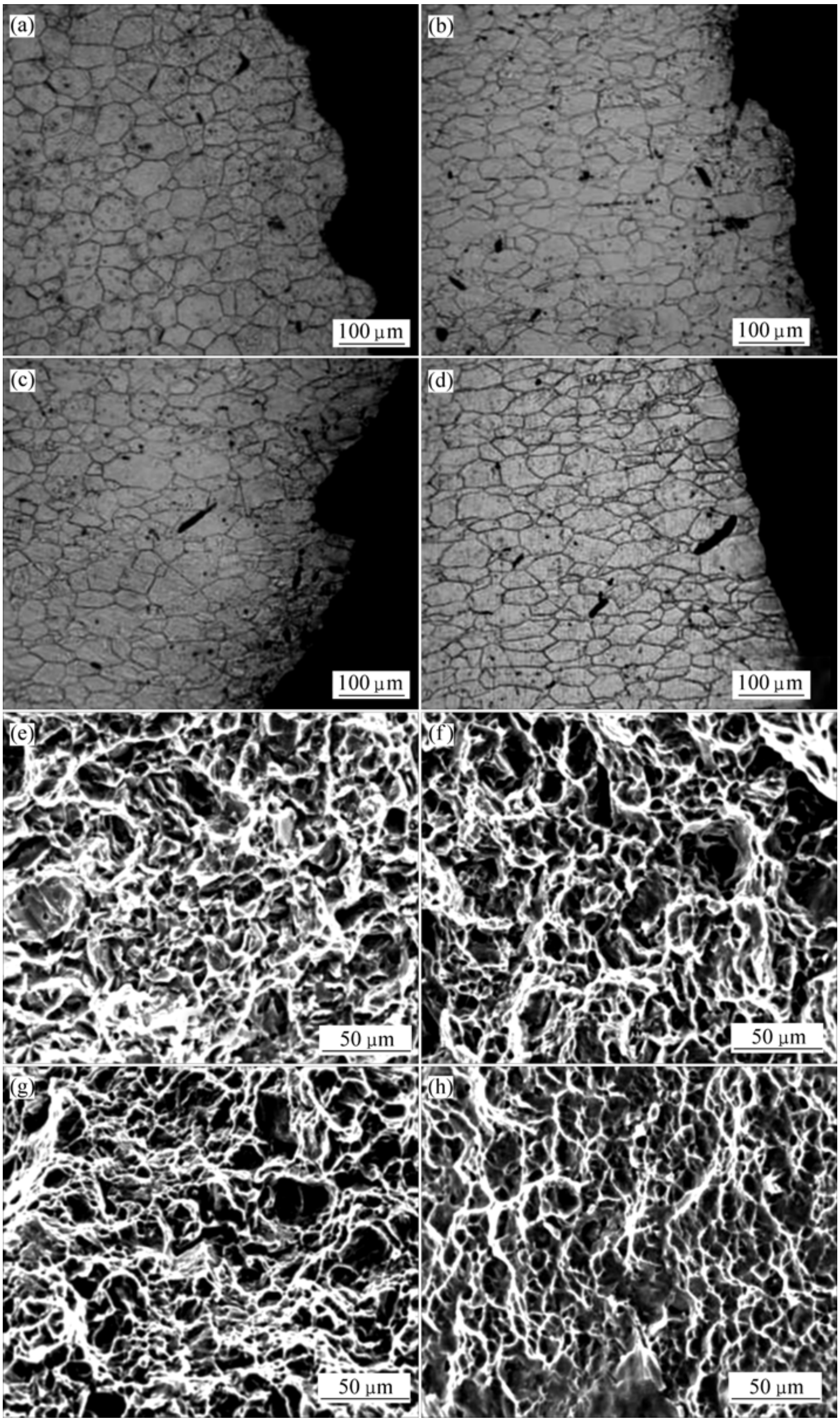

Fig.5 Optical micrographs adjacent to tensile fractured surfaces and fracture surfaces: (a)−(d) Microstructures adjacent to tensile fracture surfaces; (e)−(h) SEM morphologies of fracture surfaces; (a), (e) 25 ℃; (b), (f) 200 ℃; (c) (g) 250 ℃; (d), (h) 300 ℃

4 Conclusions

1) Aging treatment can harden the Mg-9Gd-3Y-0.3Zr extruded alloys markedly at 200−250 ℃, but the alloy has greater response to aging at 200 to 225 ℃ than at 250 ℃. The aging response at 200 ℃ is almost the same as that at 225 ℃, but the time to peak-aging at

225 ℃ is shorter than that at 200 ℃.

2) Aging treatment improves the hardness of alloys due to the increase of a great quantity fine precipitates, one kind of those precipitates is β'' phase with DO_{19} structure and the other is β' phase with bcc structure.

3) The fracture mode is mainly microvoid coalescence fracture and brittle cleavage fracture at room temperature, and microvoid coalescence fracture at 250 ℃ and 300 ℃.

References

[1] LIU Yi. Transient plasticity and microstructural evolution of a commercial AZ31 magnesium alloy at elevated temperature[D]. Wayne State University Detroit, 2003: 1−150.

[2] MORDIKE B L, EBERT T. Magnesium properties-applications-potential[J]. Mater Sci Eng A, 2001, A302: 37−45.

[3] KENTARO Y, YOSHIYUKI O, MASASHI S, HIDETSUNA W, SHIGEHARU K, YO K. Alloy development of high toughness Mg-Gd-Y-Zn-Zr alloys[J]. Materials Transactions, 2006, 47(4): 1066−1070.

[4] SOCJUSZ-PODOSEK M, LITYNSKA L. Effect of yttrium on structure and mechanical properties of Mg alloys[J]. Materials Chemistry and Physics, 2003, 80: 472−475.

[5] FRIEDRICH H E, MORDIKE B L. Magnesium Technology[M].Berlin: Springer, 2006: 603−617.

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

[7] SMOLA B, STULÍKOVÁ I, Von BUCH F, MORDIKE B L. Structural aspects of high performance Mg alloys design[J]. Mater Sci Eng A, 2002, A324: 113−117.

[8] CÍZEK J, PROCHĂZKA I, SMOLA B. Microstructure and thermal stability of ultra fine grained Mg and Mg-Gd alloys prepared by high-pressure torsion[J]. Materials Science Forum, 2005, 482: 183−186.

[9] JAKUB C, IVAN P, BOHUMIL A, IVANA S, RADOMIR K, ZDENEK M J, VIKTOR C. Thermal development of microstructure and precipitation effects in Mg-10%wtGd alloy[J]. Phys Stat A, 2006, A203: 466−477.

[10] BOHUMIL S, IVANA S, JITKA P, FRANK V B, BARRY L B. Phase transformations due to isochronal annealing of Mg-rare earth-Sc-Mn squeeze cast alloys[J]. Z Metallkd, 2003, 94: 553−558.

[11] WATANABE H, TSUTSUI H, MUKAI T. Deformation mechanism in a coarse-grained Mg-Al-Zn alloy at elevated temperatures[J]. International Journal of Plasticity, 2001, 17: 387−397.

[12] PENG Z K, ZHANG X M, CHEN J M, XIAO Y. Grain refining mechanism in Mg-9Gd-4Y alloys by zirconium[J]. Materials Science and Technology, 2005, 21(6): 722−726.

[13] KAWAHVTA T, MATSUDA K, KAMADO S, KOJIMA Y, LKENO S. HRTEM observation of the precipitates in Mg-Gd-Y-Zr alloy[J]. Materials Science Forum, 2005, 419/422: 303−306.

[14] NIE J F, MUDDLE B C. Precipitation in magnesium alloy WE54 during isothermal ageing at 250 ℃[J]. Scripta Materialia, 1999, 40(10): 1089−1094.

[15] IFEANYI-ANTHONY A, SHIGEHARU K, YO K. Aging characteristics and high temperature tensile properties of Mg-Gd-Y-Zr alloys[J]. Materials Transactions, 2001, 42: 1206−1211.

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