Advanced Materials Research Vols. 284-286 (2011) pp 1564-1567
Online available since 2011/Jul/04 at www.scientific.net

doi:10.4028/www.scientific.net/AMR.284-286.1564

Microstructure and creep property of as-cast Mg-6Al-*X*Sr(*x*=0, 2, 3) alloys

Yufeng Wu[1,a], Wenbo Du[2,b] , Yinan Zhang[2,c] , Tieyong Zuo[1,d]
[1]1. Institute of recycling economy, Beijing University of Technology, Beijing, China
[2] College of materials science and engineering, Beijing University of Technology, Beijing, China
[a]fograinwind@126.com, [b]duwb@bjut.edu.cn, [c]jeffreyzyn333@hotmail.com, [d]zuoty@bjut.edu.cn

Keywords: magnesium alloy; Sr; creep; grain boundaries sliding; dislocation motion

Abstract. The microstructure and creep property of as-cast Mg-6Al-*x*Sr(*x*=0, 2,3) alloys were studied. Results showed that the branch-like Al_4Sr phase is the main precipitating phase in these alloys containing Sr. Their secondary creep rates under the applied stress of 70MPa at 175℃ decreased with the increasing in the content of Sr and reached the minimum value of $1.4\times10^{-8}s^{-1}$ in the Mg-6Al-3Sr alloy, which is one thirtieth of secondary creep rates of the Mg-6Al alloy. It was mainly attributed to Al_4Sr, which effectively hindered the grain boundaries sliding and dislocation motion in the creep.

Introduction

It has been reported that Sr is an effective strengthening element to improve the properties of common Mg alloys such as AZ and AM series [1-4]. However, some studies indicated that the precipitating phases containing Sr in Mg-Al-Sr alloy are not entirely clear. For example, Baril etal found that Al_4Sr is the only one precipitating phase containing Sr in Mg-6Al-2Sr alloy [1]. The good creep property of Mg-5Al-2Sr alloy is attributed to Al_4Sr and Mg-Al-Sr ternary phase [2]. Pekguleryuz etal reported whether the Mg-Al-Sr ternary phase precipitates should depend on the ratio of Sr and Al in Mg-Al alloys. If the mass ratio of Sr/Al is over 0.33, the Mg-Al-Sr ternary phase should precipitate [3]. Suzuki reported that $Mg_{17}Sr_2$ precipitates in Mg-5Al-3Sr alloy instead of Mg-Al-Sr ternary phase [4]. In the present paper, the microstructure and creep property of as-cast Mg-6Al-*x*Sr(*x*=2,3) alloys are studied and the contributions of main precipitating phases to creep property are analyzed.

Experimental

The commercially pure Mg, Al (>99.99%) were first melted in a crucible electric resistance furnace under a protection of flux cover, then the Sr metal was added into the melt at 780 °C. The melt was held at 780 °C for 30 mins and poured at 730 °C into a steel mold that was kept at room temperature. The measured compositions of all studied alloys detected by inductively-coupled plasma (ICP) spectroscopy are Mg-6.1Al, Mg-5.8Al-1.9Sr, and Mg-5.9Al-2.9Sr. The actual chemical compositions of these alloys

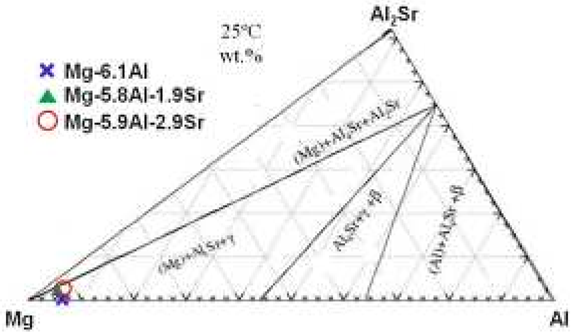

Fig.1 Partial isothermal section of the Mg-Al-Sr at 25 °C [5] with the actual compositions of key samples in the phase diagram.

are shown in the partial isothermal section of the Mg-Al-Sr at 25 °C, as illustrated in Fig. 1. They are denoted as AJ60, AJ62 and AJ63, respectively. The creep samples were 25mm in gauge length and 5.0mm in diameter. The microstructure of Mg-6Al-xSr(x=2,3) alloys were analyzed by X-ray diffraction(XRD) ,optical microscopy (OM). The thermal analysis for the melting and solidification of Mg-6Al-xSr(x=0,2,3) were be done by the NETZSCH-DSC449C at heating and cooling rates of 10℃·min^{-1}. The creep tests were performed by using CSS-3902 creep testing machine under the applied stresses of 70MPa at 175℃. In order to clarify the possible contributions of main precipitating phases in the creep, the microstructure of AJ63 alloy after creep was studied by scanning electron microcopy (SEM) and transmission electron microscopy (TEM).

Results and discussion

Microstructure of as-cast Mg-6Al-*xSr*(*x*=2,3) alloys

Fig. 2 shows the XRD patterns of as-cast Mg-6Al-xSr(x=2,3) alloys. Fig. 2 exhibits that the additional diffraction peaks of Al$_4$Sr emerge in AJ62 and AJ63 alloys. The diffraction peaks of Mg$_{17}$Al$_{12}$, Mg$_{17}$Sr$_2$ or ternary phase are not found, which indicates that these possible precipitating phases are not formed during the cooling process or their mount is too low to be detected by XRD.

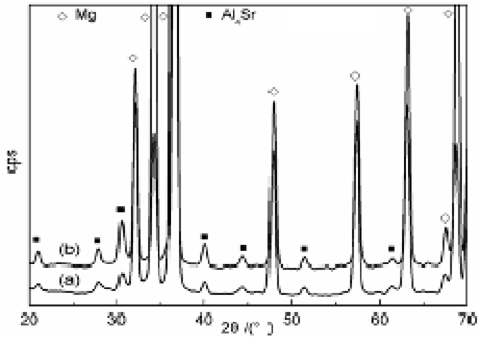

Fig.2 X-ray diffraction patterns of as-cast Mg-6Al-xSr(x=2,3) alloys
(a) AJ62; (b) AJ63

Fig. 3 shows the microstructure of as-cast Mg-6Al-xSr(x=0, 2, 3) alloys. The OM image in Fig. 3(a) exhibits that one phase is formed along the grain and dendrite boundaries in AJ60 alloy. According to the Mg-Al phase diagram, the precipitating phase is proposed to be Mg$_{17}$Al$_{12}$.The OM images in Fig. 3(b,c) exhibit that the branch-like phase is formed along the grain and dendrite boundaries in the AJ62 and AJ63 alloys. The amount of precipitating phase increases with the increasing in the amount of Sr. The dendrite arm spacing decreases with the increasing in the amount of Sr and arrives at about 50um in AJ63 alloy. According to the XRD patterns of as-cast Mg-6Al-xSr(x=2,3) alloys, the precipitating phase is proposed to be Al$_4$Sr.

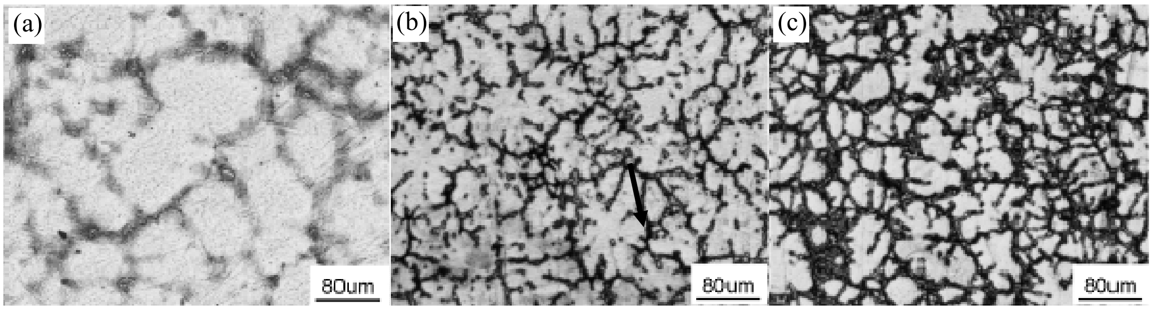

Fig.3 OM image of as-cast Mg-6Al-xSr(x=0,2,3) alloys
(a) AJ60; (b) AJ62; (c) AJ63

Fig. 4 shows the DSC curves of melting and cooling processes of Mg-6Al-*x*Sr(*x*=0,2,3) alloys. There is only one endothermic peak at about 450℃ in Fig.4 (a) for the melting process of AJ60 alloy, which is corresponding to the melting of $Mg_{17}Al_{12}$. There are two endothermic peaks for the melting process of AJ62 alloy in Fig.4 (a). One is also at about 450℃ and corresponding to the melting of $Mg_{17}Al_{12}$, which indicates that there is still a very small amount of $Mg_{17}Al_{12}$ precipitating in AJ62 alloy. But the amount is so small that it could not be detected by XRD. The other at about 520℃ is proposed to be corresponding to the melting of Al_4Sr. In Fig.4(a),there is only one endothermic peak at about 520℃ for the melting process of AJ63 alloy, which is proposed to be corresponding to the melting of Al_4Sr. The analysis as above indicates that Al_4Sr is the only one precipitating phase instead of $Mg_{17}Al_{12}$ completely in AJ63 alloy. For the cooling curves of AJ60 and AJ62 in Fig.4 (b), the exothermic peaks corresponding to the precipitating of $Mg_{17}Al_{12}$ and Al_4Sr were detected. For the cooling curve of AJ63 in Fig.4 (b), an unknown exothermic peak emerges near to that of Al_4Sr. It is deduced that the unknown exothermic peak should be corresponding to the so-called Mg-Al-Sr ternary phase [2, 3]. It implies that there is different for the transformations occurring in the melting and cooling processes of AJ63 alloy. The sample in the melting process was obtained by the steel mold cast at a high cooling rate while the sample in the cooling process had been heated to melt at a low heating rate of 10℃min^{-1}.That is to say the different cooling rates would lead to different microstructures, which are corresponding to the different transformations occurring in the heating or cooling process. This can be used to explain why the different microstructures in Mg-Al-Sr alloy are shown in different references [1-4].

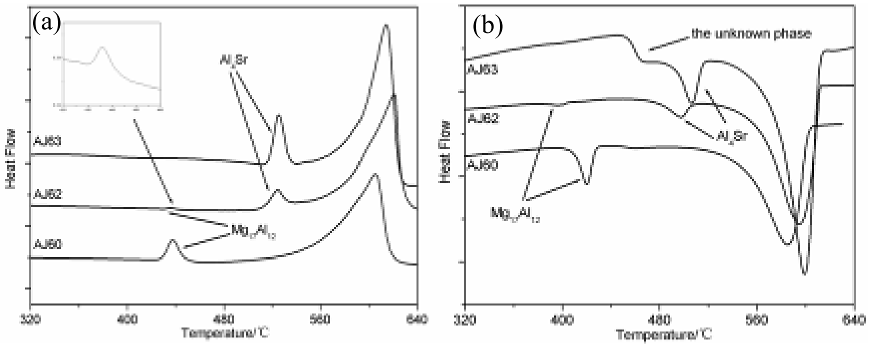

Fig.4 DSC curves for the melting and cooling processes of experimental alloys
(a) Melting process; (b) Cooling process

Creep property of as-cast Mg-6Al-*x*Sr（*x*=2,3) alloys

The creep curves of as-cast Mg-6Al-*x*Sr(*x*=0,2,3) alloys are showed in Fig.5. It indicates that the creep strains in the same time and the secondary creep rates decrease with the amount of Sr increasing. The secondary creep rate of AJ63 ($1.4\times10^{-8}s^{-1}$) reached one thirtieth of that of AJ60 ($4.5\times10^{-7}s^{-1}$).

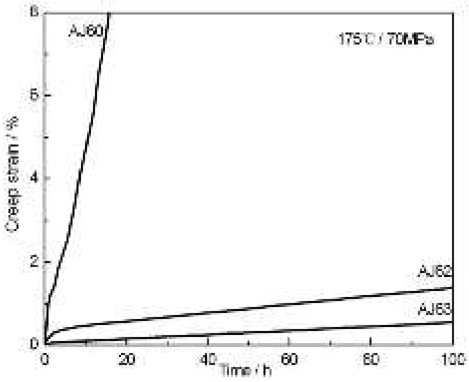

Fig. 5 Creep property of Mg-6Al-*x*Sr(*x*=0,2,3) alloys under the applied stress of 70MPa at 175℃

Taking AJ63 alloy as an example, its microstructure after creep for 100h under the applied stress of 70MPa at 175℃ was observed by using SEM and TEM and the results are listed in Fig.6. Fig.6 (a) indicates that some Al_4Sr crystallize along and across the grain boundaries, which indicates that Al_4Sr is able to hinder the grains sliding effectively. For the common Mg-Al series alloys, their creep mechanism is greatly affected by the instability of the microstructure of grains boundaries. For example, the failure of creep for AZ91 alloy is related to the precipitation of $Mg_{17}Al_{12}$ with a low melting point of 438℃ in the creep [6]. It is easy for $Mg_{17}Al_{12}$ to be softened at the temperatures for creep and is difficult to hinder the grain boundaries sliding while Al_4Sr with a high melting point is more thermally stable and hinder the grain boundaries sliding more effectively. Fig.6 (b) shows the high density dislocations emerge in the vicinity of the precipitating phase. Fig.6 (c) shows this phase is Al_4Sr (a=b=0.4463nm,c=1.1203nm) [5]. In all, the contributions of Sr to the improvement of creep property of Mg-6Al alloy was mainly contributed to the branch-like Al_4Sr phase ,which hindered the grain boundaries sliding and dislocations motion effectively in the creep of Mg-6Al alloy.

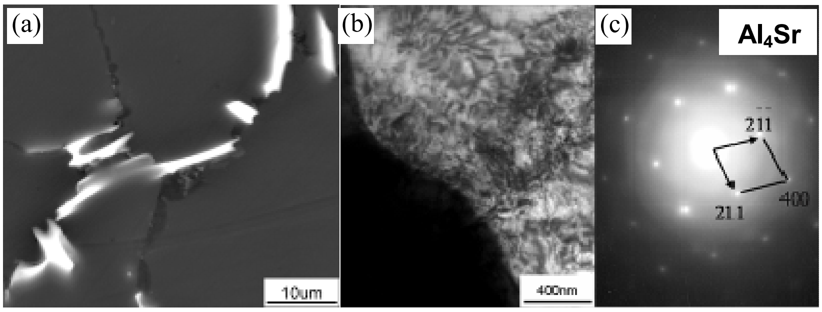

Fig.6 Microstructure changes of as-cast AJ63 alloy after creep
(a) Al_4Sr phase located in grain boundaries;
(b) High density dislocations in the vicinity of precipitating phase; (c) SADP of precipitating phase

Conclusions

(1) The branch-like Al_4Sr phase is the main precipitating phase in as-cast Mg-6Al-*x*Sr(*x*=2,3) alloys at a high cooling rate. Whether the Mg-Al-Sr ternary phase precipitates should be related to the solidification conditions.

(2) The secondary creep rates of Mg-6Al-*x*Sr(*x*=0,2,3) alloy decreased with the content of Sr increasing and reached the minimum value of $1.4\times10^{-8}s^{-1}$ at the content of 3.0.%Sr, which is one thirtieth of that of AJ60 alloy. It was mainly attributed to Al_4Sr, which hindered the grain boundaries sliding and dislocation motion effectively in the creep.

Acknowledgements

This work is financially supported by Project of Key Disciplines Development: "Resources, Environment and Recycling Economy" Interdisciplinary under the Jurisdiction of Beijing Municipality (No. 0330005412901) and Project for the young and middle-aged outstanding teachers supported by Beijing Municipal Education Commission (No. PHR20110843)

References

[1] E.Baril, P.Labelle, M.O.Pekguleryuz: *JOM*. Vol.11 (2003), p. 34
[2] Y.Zhong, K.Ozturk,Z.K.Liu: TMS. *Magnesium technology* (2002), p. 69
[3] M.O.Pekguleryuz, E. Baril: *Mater.Tras*. Vol.42(2001), p.1258
[4] A. Susuki,N.D.Saddock,L.Riester: *Metal.Mater.Trans.A*. Vol.38 (2007), p.420
[5] M.A. Parvez, M. Medraj, E. Essadiqi, A. Muntasar, *J. Alloys Comp*.Vol.402 (2005), p.170
[6] T.G. Langdon: *Mater. Sci. Eng. A* Vol. 283(2000), p. 266

Materials and Design
doi:10.4028/www.scientific.net/AMR.284-286

Microstructure and Creep Property of As-Cast Mg-6Al-<i>X</i>Sr(<i>x</i>=0, 2, 3) Alloys
doi:10.4028/www.scientific.net/AMR.284-286.1564