Science Press

Trans. Nonferrous Met. Soc. China 17(2007) s372−s375

Transactions of Nonferrous Metals Society of China

www.csu.edu.cn/ysxb/

Superplasticity of Mg-Gd-Y alloy in tensile test at elevated temperature

XIAO Yang(肖 阳), ZHANG Xin-ming(张新明), DENG Yun-lai(邓运来), FAN Xiao-hui(范晓慧)

School of Materials Science and Engineering, Central South University, Changsha 410083, China

Received 15 July 2007; accepted 10 September 2007

Abstract: The high tensile ductility of Mg-Gd-Y alloy at temperatures above 623 K and average engineering strain rate of $4.6\times 10^{-4}\,s^{-1}$ was investigated. The results show that the high ductility (elongation 77%) at 623 K is attributed to the basal, non-basal dislocations glides. The superplasticity deformation (elongation 180%) at 673 K includes three stages. The first stage is the plastic deformation induced by dislocation gliding and twining. The second stage is the grain refinement controlled by dynamic recrystallization. The third stage includes two processes of the fine grain growth and grain refinement of the elongated grain with high stored energy.

Key words: Mg-Gd-Y; ductility; superplasticity; microstructure

---

1 Introduction

Magnesium-rare earth (Mg-RE) alloys present a great potential as heat resistance light metal materials in the aerospace and automobile industries mainly because of their low densities. An important disadvantage of Mg alloys is their low ductility, which limits their formability. Fortunately, it has been reported that superplastic flows occur in fine-grained magnesium alloys, even in coarse-grained magnesium alloys[1−4]. These fine-grained magnesium alloys, including P/M WE54 (Mg-Y-Nd alloy), deform principally by a grain boundary sliding mechanism[1−2]. It has also been found that the high tensile ductilities associated with superplasticity of coarse-grained Mg-Al alloys are attributed to dislocation glide/climb-controlled creep mechanisms and/or continuous recrystallization controlled by lattice diffusion[3−4]. However, there are few literatures about deformation mechanism of Mg-Gd-Y heat-resistance alloy at elevated temperatures up to 673 K (above 0.75 T_m).

In the present work, the high tensile ductility of an Mg-Gd-Y alloy at elevated temperatures of 623 K and 673 K was investigated, and the microstructural evolutions during tensile tests were also studied.

2 Experimental

The material used in the present study was a Mg-9.0Gd-4.0Y-0.6 Zr (mass fraction, %) alloy in the form of extruded rod with a diameter of 15 mm[5−6]. The extruded rod was aged at 498 K for 24 h (as Ext-T5). A typical optical microstructure of the as Ext-T5 material is shown in Fig.1. The grains were almost equiaxed. The average linear intercept size of the grains is about 40 μm.

Cylindrical tensile specimens, cut from the as Ext-T5 rods and machined, had a gauge length of 36 mm, diameter of 6.0 mm. Tensile tests were carried out at temperatures ranging from 623 K to 673 K and constant velocity of the moving clamp of 1 mm/min (the average engineering strain rate of about 4.6×10^{-4} s^{-1}) in air. After tensile test, one part of the fractured specimen was cooled in water immediately to maintain the hot deformed microstructures. The microstructures were determined with XJP-6A optical microscope(OM) and Tecnai $G^2$20 transmission electron microscope(TEM).

3 Results

3.1 Effect of temperature on tensile ductility

Foundation item: Project(51330) supported by the National Basic Research Program of China

Corresponding author: ZHANG Xin-ming; Tel: +86-731-8830265; E-mail: xmzhang@mail.csu.edu.cn

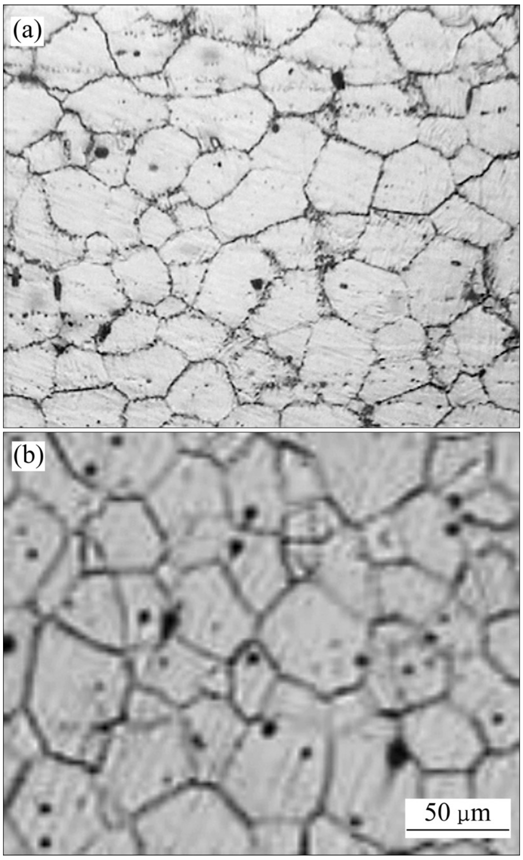

Fig.1 Initial optical microstructures in as Ext-T5 specimen of Mg-9.0Gd-4.0Y-0.6Zr alloy: (a) Extrusion direction; (b) Transverse direction

Fig.2(a) shows typical fractured specimens tested at elevated temperatures, and indicates that the fractured morphologies are along the direction of maximum shears according to crack trend in macroscopic view. The elongations are 77% and 180%, at temperatures of 623K and 673K, respectively. The corresponding loading force—displacement curves are shown in Fig.2(b).

The curve at 623 K in Fig.2(b) has a significant peak, after the peak, the loading force rapidly decreases until fracture occurs, indicating that instable plastic flow occurs after the peak corresponding to the elongation of about 10%. Moreover, the curve at 623K becomes serrated after the peak. The curve at 673 K in Fig.2(b) becomes finely serrated after being stretched to the elongation of about 10%, but no obvious peaks appear. In other words, the stable plastic flow has reached 180% before stage Ⅲ plastic deformation occurs.

In short, the tensile ductility of the present coarse-grained Mg-Gd-Y alloy is associated with deformation temperature. High ductile fracture occurs at 623 K. There is doubt that the superplasticity occurs at 673 K.

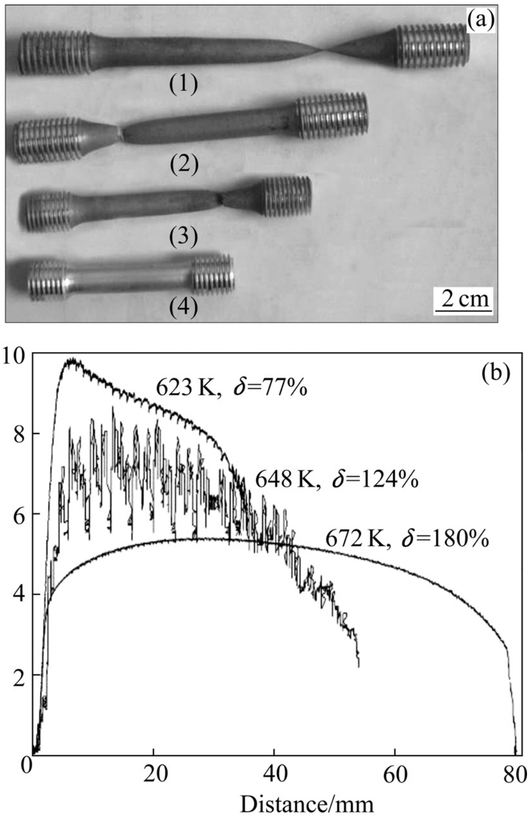

Fig.2 Typical fractured specimens after being tensioned (a) and their loading force—displacement curves in tensile processes (b)

3.2 Microstructural evolution

Fig.3 shows the optical micrographs of a nicking zone and an area away from the nick cut along the tensile axis of the tensioned cylindrical specimen at 623 K. It is found that some grains are elongated along the loading force direction. The cavities are mainly developed and extended at the junctions of three grains. This interprets that the serrated segment of the loading force—displacement curve at 623 K in Fig.2(b). Twining and recrystallization grains are not found. It is clear that the fracture occurs along weak grain-boundary at 623 K as expected in polycrystalline metal material.

Fig.4 shows the optical micrographs of a nicking zone and an area away from the nick cut along the tensile axis of the tensioned cylindrical specimen at 673 K. It is found that almost all grains are elongated along the loading force direction. Cavities are not found. Twining and fine grains are found. The twining occurs within coarse grains, and fine grains appear on the zones near the coarse grains boundaries. The fine grains boundaries are difficult to identify in present optical micrographs. It is clear that the mechanisms of deformation and fracture at 673 K are different from those at 623 K.

It is revealed by the TEM micrographs in Fig.5(a) that fine grains are developed in the fractured specimen at 673 K. The fine grain sizes are 3−5 μm. Moreover, the fine grains show three morphologies in Fig.5(a): 1) the new fine grains, labeled as *A*, *B*, *C*; 2) the grain including subgrain boundaries, labeled as *D*; and 3) the grain with dislocation structures, labeled as *E*, which is amplified in Fig.5(b). Furthermore, it is found in Fig.5(a) that the new grains, labeled as *A*, *B*, *C*, can grow into grain *E*, in which the dislocation structures and greyness imply higher stored energy.

4 Discussion

4.1 Twining at elevated temperature

It is interesting for observation of twinning on superplasticity of Mg-Gd-Y coarse-grained alloy, which has not been reported by other researchers.

It is shown in Fig.3 that some grains are elongated at 623 K, indicating that the basal and non-basal gliding

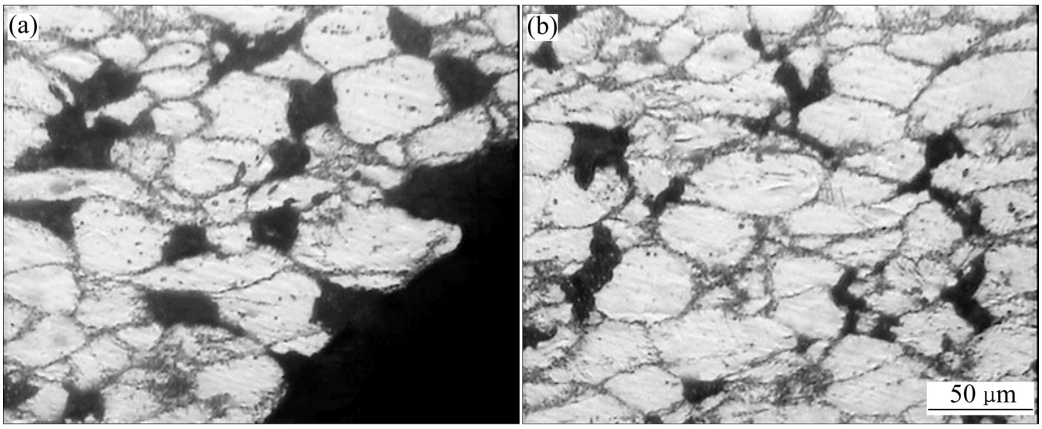

Fig.3 Optical microstructures of extruded Mg-9Gd-4Y-0.6Zr-T5 alloy tensioned at 350 ℃: (a) Longitudinal section before tensile; (b) Longitudinal section after tensile

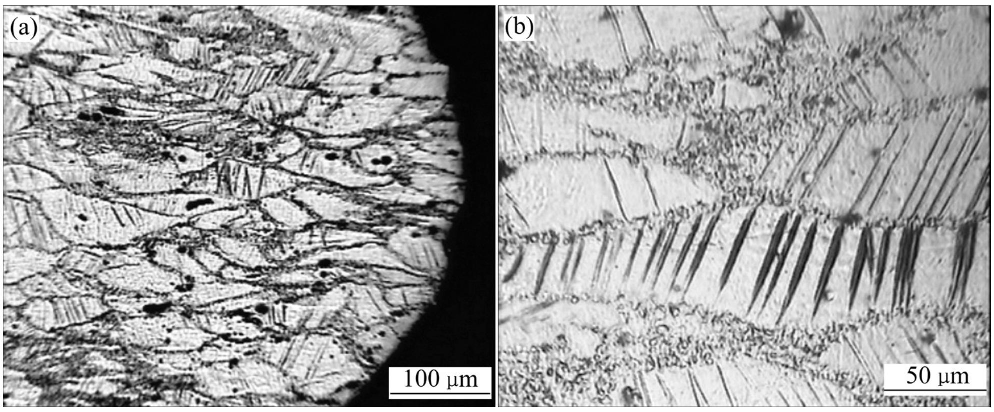

Fig.4 Optical micrographs of nicking zone (a) and area away from nick (b) cut along tensile axis at 673 K

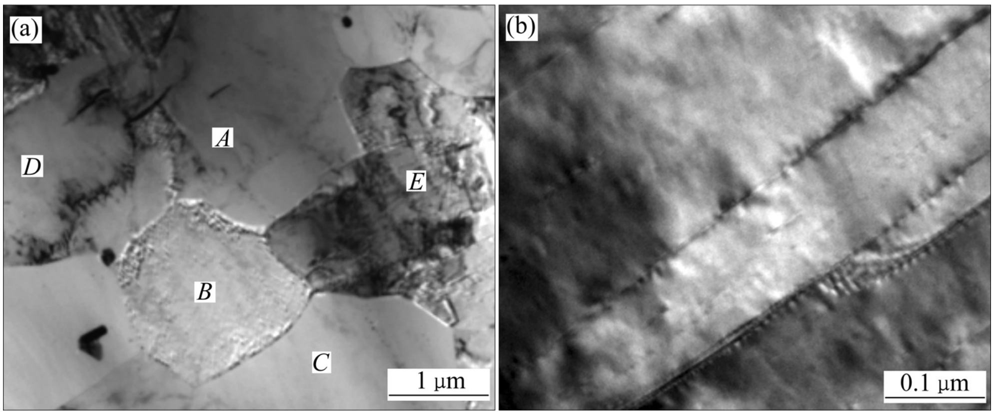

Fig.5 TEM micrographs of specimen tensioned at 673 K: (a) Morphology of developed fine grains; (b) Reign with dislocation structures

systems can be activated at temperatures above 623 K, which should contribute to the high ductility (77%). Considering temperature-dependent effect of the activated non-basal gliding systems of HCP magnesium, it should be accepted that almost all the grains are elongated at 673 K in Fig.4, which should contribute to the higher ductility than that at 623 K.

It should be noticed in Fig.4 that the first order coarse twins at 673 K are orientated on two symmetrical directions along the tensile axis, indicating that twins occur when the grains turn to the twining-orientation. Compared with no twins in the elongated grains microstructures at 623 K in Fig.3, it is suggested that the value of the critical resolved shear stress(CRSS) of twining rapidly decreases with increasing temperature, and it is almost equal to that of the dislocation gliding for Mg-Gd-Y alloy at 673 K. In other words, twining system is an effective active gliding system. In short, the present twins at 673 K should be attributed to the reorientations of the deformed grains and the temperature-dependent rates of critical resolved shear stresses of twinning systems to gliding systems.

4.2 Mechanism of superplasticity

There is no doubt that the present superplasticity is caused by the fine grains developing in regions near the initial coarse grains boundaries and lots of the elongated grains. The present superplasticity and the associated microstructural evolution are neither as Class I type creep, in which there are no elongated grains in microstructures, nor as continuous recrystallization, in which the initial grains are refined by recrystallization [7].

In the present investigation, there is no sufficient supplement on the mechanism of the grain refinement, but the regions embraced by new fine grains in Fig.5(a) imply that a dynamic recrystallization should occur in the tensile process. Moreover, only the recrystallization can consist with the fine serration on the loading force-distance curve in Fig.2(b). Furthermore, twining in the elongated grains indicates that the initial grains have been heavily deformed and store high strain energy, which supplies the potential of recrystallization.

Up to now, the present deformation mechanism of the superplasticity of Mg-Gd-Y alloy at 673 K can be suggested as the following three stages. In the first stage, the initial grains are mainly elongated and reoriented by the basal and non-basal dislocations glides[8]. The presented twins are caused by the reorientations of the deformed grains and the decrease of the temperature-dependent CRSS of twinning. The second stage, the grain refinement stage, is a dynamic recrystallization. It is firstly developed on the regions the boundaries between the deformed grains because of the higher stored energies compared with the inner parts of the grains. The third stage includes two processes of the fine grain growth and grain refinement of the elongated initial grain with high stored energy.

5 Conclusions

1) The high ductility of the specimens tensioned at 623 K is attributed to the basal, non-basal dislocations glides, and the fracture is induced by the grains boundaries weakening at elevated temperatures.

2) The superplasticity of the specimens tensioned at 673 K includes three stages. The first stage is the plasticity deformation induced by dislocation gliding and twining. The second stage is the grain refinement controlled by dynamic recrystallization. The third stage includes two processes of the fine grain growth and grain refinement of the elongated grain with high stored energy.

References

[1] WU X, LIU Y. Superplasticity of coarse-grained magnesium alloy [J]. Scripta Materialia, 2002, 46: 269−274.

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

[3] 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.

[4] WESLING V, RYSPAEV T, SCHRAM A. Effect of overageing temperature on the superplastic behaviour in magnesium alloys [J]. Materials Science and Engineering A, 2007, 462: 144−148.

[5] ZHANG X. M, XIAO Y. Fracture mechanism analysis of Mg-9Gd-4Y-0.6Zr alloy [J]. Materials Science Forum, 2007, 546/549: 261−266.

[6] XIAO Yang, ZHANG Xin-ming, CHEN Bu-xiang. Properties investigation of Mg-9Gd-4Y-0.6Zr alloy [J]. Trans Nonferrous Met Soc China, 2006, 16(s3): 1669−1672.

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

[8] KIM W J, CHUNG S W, CHUNG C S. Superplasticity in thin magnesium alloy sheets and deformation mechanism maps for magnesium alloys at elevated temperatures [J]. Acta Materialia, 2001, 49: 3337−3345.

(Edited by PENG Chao-qun)