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Isothermal fatigue behaviours of Mg-12Gd-3Y-0.5Zr magnesium alloy at elevated temperatures

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Abstract. Isothermal fatigue tests were carred out on Mg-12Gd-3Y-0.5Zr magnesium alloy and its heat-treated counterpart at different temperatures. The exprimental results shows that isothermal fatigue strength of two alloys decrease very slowly with increasing temperature up to 200℃. The ultimate tensile strength of heat-treated Mg-12Gd-3Y-0.5Zr is slight lower than that of as-rolled counterpart, however, the fatigue strength of heat-treated alloy is higher.

1 Introduction

Magnesium alloys are called green-engineering materials with great development potential because of their many outstanding advantages, such as low density, high specific strength and specific stiffness, good machinability and castability, etc.[1]. Numerous magnesium alloy products have been used in automobile, communication and aerospace industries [2]. However, there are some serious shortcomings, one of which is poor mechanical property at high temperature that limits the applications of magnesium alloys in the corresponding conditions. In recent years, many attempts have been made to improve the mechanical properties of magnesium alloys. Equal channel angular pressing (ECAP), as one effective method of severe plastic deformation (SPD), can modify the microstructure and texture of magnesium alloys and improve the tensile properties to some extent [3].

In this paper, the ultimate tensile strength and isothermal fatigue strength at different temperatures are reported. With added rare earth elements, the as-rolled and heat-treated Mg-12Gd-3Y-0.5Zr alloys show the high tensile strength and decent fatigue strength at elevated temperatures. The strengthening and the fatigue failure mechanisms are discussed in this paper.

2 Experimental

The ingots of Mg-12Gd-3Y-0.5Zr alloy were rolled with a ratio of 25:1 at 400 ºC. For comparison，part of the as-rolled alloy was further heat-treated in a furnace at 415 ºC for 16 hours and then cooling in air.

Tensile and isothermal fatigue specimens were cut by electric spark machining along the rolling direction with a gauge sections of 3mm×1.4mm×1mm^3 and 20mm×4mm×3mm^3 respectively. Tensile tests were carried out on an Instron 8801 testing machine equipped with a heater and temperature controlling system at room temperature, 130, 170, 200 and 235 ºC and at a strain rate of $1\times10^{-3}s^{-1}$. Isothermal fatigue tests were carried out on an MTS810 testing machine at room temperature, 100, 200 and 235 ºC and at a frequency of 20Hz under stress control. The stress wave form was triangular, and the load ratio R=0.1.

The fracture surface morphologies of the specimens were observed by a Cambridge S360 scanning electron microscope (SEM). For TEM observations, slices with a thickness of 0.6mm were cut from the section parallel to the rolling direction, mechanically thinned to about 50μm and cut into discs with diameters of 3mm. Thin foils were made from these discs with a twin-jet polisher with a current of 40μA using an electrolyte of 20% HNO_3 in methanol at 248 K. The thinned foils were observed using a TEM 2000FXⅡoperating at 200 KV.

3 Experimental results and discussion

3.1 Tensile properties at different temperatures

Temperature dependence of ultimate tensile strengths of the as-rolled and heat-treated Mg-12Gd-3Y-0.5Zr alloys is shown in Fig. 1 for tests carried out at room temperature, 130, 170, 200 and 235 ºC. Ultimate tensile strength of the as-rolled Mg-12Gd-3Y-0.5Zr reaches the highest at 405 MPa at room temperature. Ultimate tensile strength of the heat-treated Mg-12Gd-3Y-0.5Zr is a bit lower than that of the as-rolled alloy at corresponding

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temperatures. Fig. 1 indicates that the ultimate tensile strengths of the as-rolled and heat-treated alloys decrease very slowly with increasing temperatures up to 200ºC which is desirable for high temperature applications obviously. However, the ultimate tensile strengths of both as-rolled and heat-treated alloys dropped apparently at 235 ºC possibly due to new slip system of magnesium alloys activating at nearly 220 ºC.

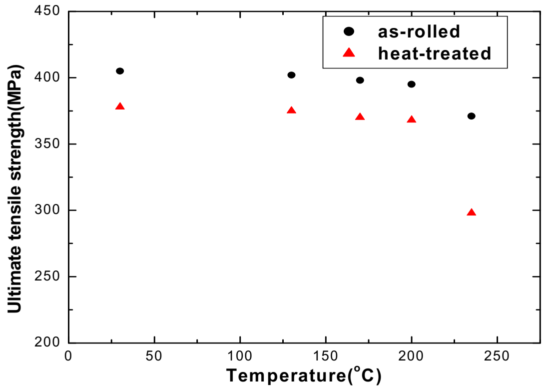


Figure 1. Temperature dependence of ultimate tensile strengths for the as-rolled and heat-treated Mg-12Gd-3Y-0.5Zr alloys.

3.2 Fatigue behaviors at different temperatures

Isothermal fatigue tests were performed at different temperatures under stress control. Figs.2a-c demonstrate the isothermal S-N curves of the as-rolled Mg-12Gd-3Y-0.5Zr at room temperature and 235 ºC, and the heat-treated alloy at 235 ºC, respectively. All tests were carried out on an MTS810 fatigue testing machine at a constant frequency of 20Hz. The isothermal fatigue strength at 5×10^6 cycles was obtained as shown in Fig.3a. The dependences of the ratio of fatigue strength over ultimate tensile strength on temperatures for the as-rolled and heat-treated Mg-12Gd-3Y-0.5Zr alloys are shown in Fig.3b. The ratio is within a range of about 0.5 to 0.2 when the temperature varies from ambient temperature to 200ºC.

From Figs.2 and 3, we can see that although the heat-treated Mg-12Gd-3Y-0.5Zr has slight lower ultimate tensile strength than that of as-rolled counterpart, it has higher fatigue strength. It means that in the cyclic loading condition, the heat-treated alloy would be preferential to be used at the temperatures ranged from ambient up to 200 ºC. However, when the temperature reaches 235 ºC, both the as-rolled and heat-treated alloys would not be used due to their fatigue strengths decreasing drastically. It is believed that fatigue strength increases with increasing ultimate tensile strength and/or increasing elongation-to-failure[4,5]. Higher elongation-to-failure of heat-treated Mg-12Gd-3Y-0.5Zr offsets the negative effect of its lower ultimate tensile strength and finally the higher fatigue strength can be achieved at different temperatures except 235 ºC.

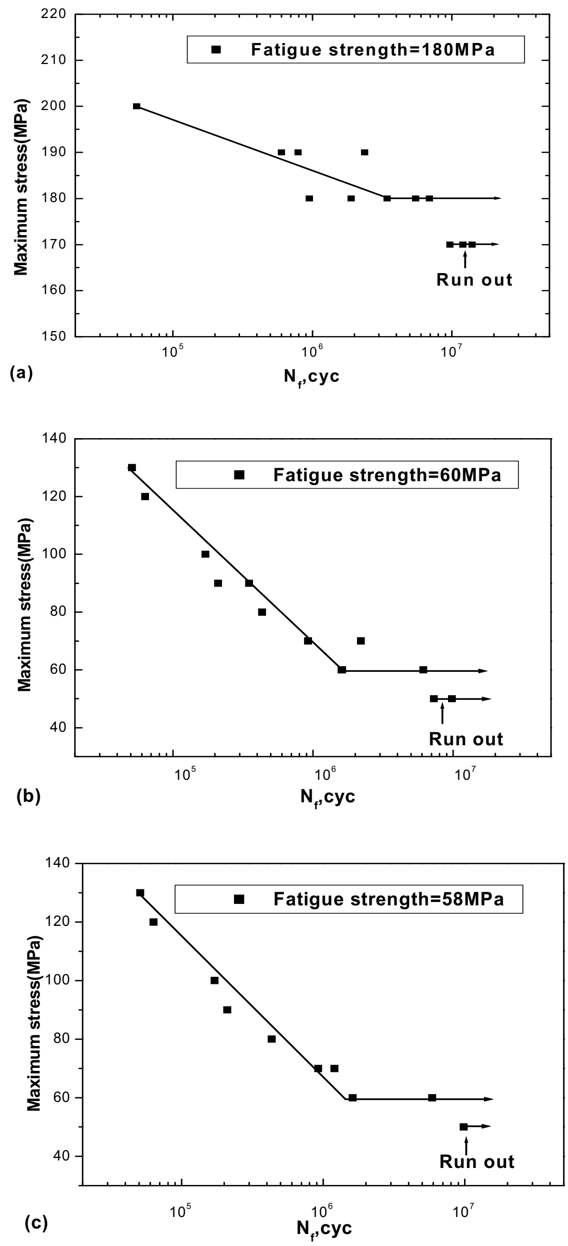
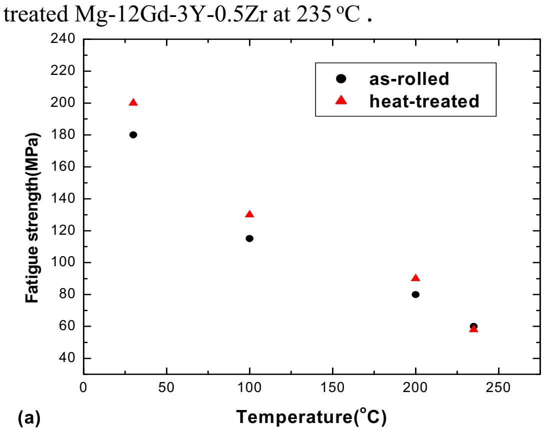


Figure 2. S-N curves of the as-rolled Mg-12Gd-3Y-0.5Zr (a) at room temperature, (b) at 235 ºC, (c) S-N curve of the heat-treated Mg-12Gd-3Y-0.5Zr at 235 ºC .



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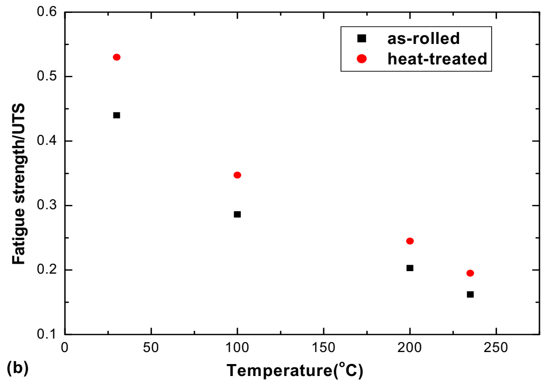
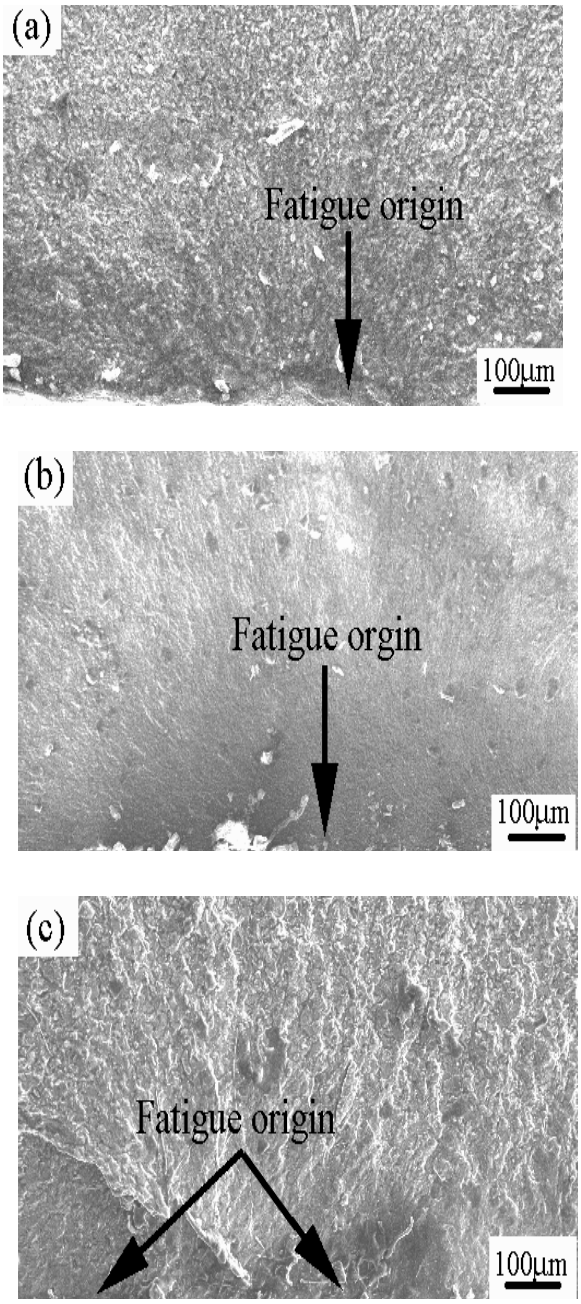


Figure 3. (a) fatigue strength vs temperature and (b) the ratio of fatigue strength over ultimate tensile strength vs temperature for the as-rolled and heat-treated Mg-12Gd-3Y-0.5Zr alloys.

3.3 Fatigue crack origins

Some of the fatigue crack initiation sites of the as-rolled and heat-treated Mg-12Gd-3Y-0.5Zr alloys tested under different stresses and at different temperatures are shown in Fig. 4. In the present experiment, it is noted that all of fatigue crack origins initiated at the sample surface no mater what stresses and temperatures applied. Ridges are obviously observed on the facture surface as shown in Fig. 4c which indicates that it has characteristic of multiple fatigue origins as marked by arrows with increasing temperatures. Similar to Fig. 4c, there are several fatigue crack origins in Fig. 4d due to high cyclic stress applied, however, the fatigue crack propagation zone is rather smooth for heat-treated alloy than that for as-rolled alloy observed in low magnification. The reason is partly due to more precipitate occurring in the heat-treated alloy which restricts the crack meandering.

In the extruded magnesium alloys without RE element additions, for example AZ31, usually the yield stress asymmetry between tension and compression caused by texture and twining exists. We found that twining and detwining [6] play key roles for crack initiation in the low cycle fatigue for AZ31. At the same time, the work in our group revealed that twining-involved fatigue damage process could also play a important role in the very high cycle fatigue regime for AZ31. However for Mg-12Gd-3Y-0.5Zr alloy the reasons for fatigue crack not be observed to initiate from twinning-detwining process may be as follows. In the present extruded alloys the texture is weak and no obvious yield asymmetry exists, in other words, twining and detwining during deformation are rare. Under isothermal fatigue test above 100ºC, cyclic slip was the main form of plastic deformation and the cyclic twining and detwining would not take place substantially. During cyclic deformation the persistent slip leads to surface roughening which makes it possible for the crack to initiate at surface, particularly, at the position where the slip band impinges with the oxide inclusion or large second phase. At the same time environmental effect plays an important role in crack initiation for these two alloys tested at high temperatures. Oxides formed at the surface make the surface roughening and embrittlement, and the crack is prone to initiate around the oxides. It can be observed from Fig. 4b that there are some oxides near the crack initiation sites. As a result, cyclic slip combined with environmental effect may be the main crack initiation mechanism. RE element additions result in dispersion of second phases and fine grains which restrains the fatigue crack growth and hence improves fatigue strengths of the as-rolled and heat-treated Mg-12Gd-3Y-0.5Zr alloys.



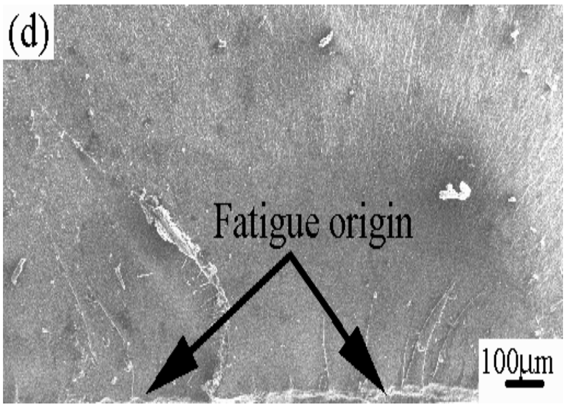


Figure 4. SEM photographs of fatigue origin: as-rolled Mg-12Gd-3Y-0.5Zr tested at (a)100℃,σ_a=110MPa, N_f=1.17×10^7cyc; (b) 200℃, σ_a=80MPa, N_f=2.42×10^6cyc; (c) 235℃, σ_a=50MPa, N_f=9.82×10^6cyc; heat-treated Mg-12Gd-3Y-0.5Zr tested at (d) 100℃, σ_a=130MPa, N_f=1.2×10^6 cyc.

4 Conclusions

(1) The as-rolled and heat-treated Mg-12Gd-3Y-0.5Zr alloys have a good combination of ultimate tensile strength and ductility at temperatures from ambient up to 200^{o}C.

(2) The ultimate tensile strength of the heat-treated Mg-12Gd-3Y-0.5Zr alloy is slightly lower than that of the as-rolled counterpart, however, the fatigue strength of the heat-treated Mg-12Gd-3Y-0.5Zr alloy is higher than that of the as-rolled alloy.

(3) Fatigue crack initiates at the surface and has the characteristic of multiple fatigue origins with increasing temperatures and/or high cyclic stresses. Precipitates in the two alloys play essential roles in the tensile and fatigue tests.

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References

1. W. J. Kim, S. W. Chung, C. S. Chung, D. Kum. Acta Mater. **49**, 3337(2001)
2. M.H. Idris: AFS Trans. **104**, 237（1996）
3. R.E. Brown: Light Metal Age. **55** (7-8), 72(1997)
4. Y. Yang and Y. B. Liu, Mater. Characterization. **59**, 567(2008)
5. X. M. Yang, H.J Yang, F. Yang, S.M. Yin, W. Wang, S.X. Li, Q.D. Wang. J. Mater. Sci. Technol. **25(6)**,731(2009)
6. S.M. Yin, F. Yang, X.M. Yang, S.D. Wu, S.X. Li and G.Y. Li: Mater. Sci. Eng. A. **494,** 397(2008)