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Full length article

High cycle fatigue behavior of the forged Mg–7Gd–5Y–1Nd–0.5Zr alloy

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Abstract

This paper investigated the high cycle fatigue behavior of a forged Mg–7Gd–5Y–1Nd–0.5Zr alloy with different stress concentration factor ($\boldsymbol{K}_t$), under different stress ratio ($\boldsymbol{R}$), and along different loading direction. The smooth specimen ($\boldsymbol{K}_t = 1$), under $\boldsymbol{R} = 0.1$ and along longitude direction, shows a high fatigue strength of 162 MPa at 10^7 cycles. The fatigue behavior of the forged Mg–7Gd–5Y–1Nd–0.5Zr alloy exhibits a high sensitive to the notch. Moreover, change of stress ratio from 0.1 to −1 may also result in a bad fatigue property. The flux inclusions were elongated along longitude direction and/or transverse direction during the forging process of the Mg–7Gd–5Y–1Nd–0.5Zr alloy. The interface between the flux inclusion and the matrix may debond and serve as the crack initiation site during the fatigue loading process, leading to the deterioration of the fatigue property along thickness direction and a high anisotropic fatigue behavior between longitude direction and thickness direction.

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Keywords: Magnesium alloy; Forge; High cycle fatigue; Stress ratio; Inclusion

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1. Introduction

Low density, high specific strength and stiffness make Mg alloys very attractive as structural materials in applications of aircraft, space ship and ground transport, where weight saving is of great importance [1,2]. Among them, Mg alloys containing rare earth elements (RE) have received considerable interest in recent years due to their potential for achieving higher strength and better creep resistance at elevated temperatures [3]. The most successful commercial Mg–RE alloys have been those based on the Mg–Y–Nd system, such as WE54 and WE43 alloy. Recently, it has been reported that the new-developed Mg–Gd–Y system alloys showed considerable precipitation hardening, and therefore present higher strength at both room and elevated temperatures and better creep resistance than WE54 alloy, and even conventional Al alloys. For instance, the ultimate tensile strength (UTS), yield strength (YS), and elongation of the extruded Mg–7Gd–5Y–1Nd–0.5Zr alloy can reach 415 MPa, 340 MPa, and 10%, respectively [4], which is suitable to serve as load bearing parts applied in the future automobiles [5].

As far as structural loading parts are concerned, the fatigue property of the alloys is instrumental in the design of safe application. However, up to now, very few of researches were focused on the fatigue behavior of the wrought Mg–7Gd–5Y–1Nd–0.5Zr alloy. In this paper, the high cycle fatigue behavior of a forged Mg–7Gd–5Y–1Nd–0.5Zr alloy was investigated systematically. The effects of notch, stress ratio, loading direction and inclusion on the fatigue strength, fatigue life and failure mechanism were discussed.

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Table 1
Analyzed chemical compositions of the investigated alloy (wt.%).

Alloy	Gd	Y	Nd	Zr	Mg
GWN751	7.79	4.47	1.04	0.62	Bal.

2. Experimental procedures

The forged Mg alloy denoted as GWN751 were examined in the present study, and its nominal composition was Mg–7Gd–5Y–1Nd–0.5Zr (wt.%). The actual chemical compositions were determined using the inductively coupled plasma (ICP) technique, and the results are listed in Table 1.

For the high cycle fatigue test, two kinds of specimens, notched specimen and smooth specimen, were used, with the stress concentration factor ($\boldsymbol{K}_t$) of 3 and 1, respectively. The dimensions of the high cycle fatigue specimens are presented in Fig. 1, in accordance with the Aviation Industry Standard of China (HB 5287-96) [6]. The axial direction of the fatigue specimen is parallel either to the longitude direction (LD) or to the normal direction (ND, i.e. the thickness direction), of the forged GWN751 alloy. Fatigue tests were conducted on the PLG-100C high-frequency fatigue test machine, under load control of pull–pull or pull–push way, with the stress ratio of $\boldsymbol{R} = 0.1$ or $\boldsymbol{R} = -1$ and a resonance frequency of 120 kHz. These tests were performed at room temperature and in air, cycling up to 10^7 cycles except for failure.

For microstructure observations, samples were cut from the forged GWN751 alloy and etched by a solution of 4 vol.% HNO_3 in ethanol after mechanical polishing to reveal grain boundaries. The average grain sizes (d) were determined by analyzing the optical micrographs with the mean linear intercept method, where $d = 1.74L$; and L is the linear intercept length. The phases were analyzed by a scanning electron microscope (SEM, Philips XL30 ESEM-FEG/EDAX) equipped with an energy-dispersive X-ray (EDX) spectroscopy analysis system. Texture analysis of the forged sample in LD-TD (TD: transverse direction) plane was performed using the Schultz reflection method by X-ray diffraction. Calculated pole figures were obtained with the DIFFRAC^{plus} TEXEVAl software, using the measured incomplete {0002}, {10–10} and {10–11} pole figures.

Tensile specimens with 25 mm in gauge length and 5 mm in gauge diameter were machined from the forged GWN751 alloy. The tensile tests were carried out along the LD and ND, respectively, at room temperature with an initial strain rate of $1 \times 10^{-3}\ s^{-1}$.

3. Results and discussion

3.1. Microstructure and mechanical properties

Typical microstructures of the forged GWN751 alloy are shown in Fig. 2. As we can see in Fig. 2a, the forged GWN751 alloy has equiaxed grain structures with an average grain size of ~32 μm, which means that complete recrystallization occurred during the forging process. The BSD microstructure, got by SEM in Fig. 2b, revealed the morphology and distribution of the second phase in the matrix. Some coarse cuboid-shaped phases distribute along the LD, and present the flow line. As previously reported [7], the cuboid-shaped phase may be the Mg_5(Gd, Y), undissolved and coarsening during the solution treatment. Moreover, a large amount of fine particles smaller than 5 μm homogeneously distribute in the matrix. Similar results appeared in the Ref. [8]; many fine particles dynamic precipitated during the multi-axial forging process of GWN751 alloy, and were identified as β phase with face-centered cubic crystal structure ($a = 2.22$ nm).

Fig. 3 presents the (0002) and $(10\bar{1}0)$ plane pole figures of the forged GWN751 alloy on LD-TD plane. It shows quite a weak texture with the maximum intensity of 2.28 m.r.d. (multiples of random distribution), which is much lower than that of the rolled Mg alloy sheet containing mass RE element (usually higher than 10 m.r.d.) [9]. Concerning on the (0002) plane pole figure, it contains many comparatively high intensity zones with the peak intensity higher than 2 m.r.d.. These high intensity zones can be divided into two parts, i.e. the basal texture component with the (0002) planes parallel to the LD-TD plane, and the non-basal texture component with the (0002) planes perpendicular to the LD-TD plane of the forged GWN751

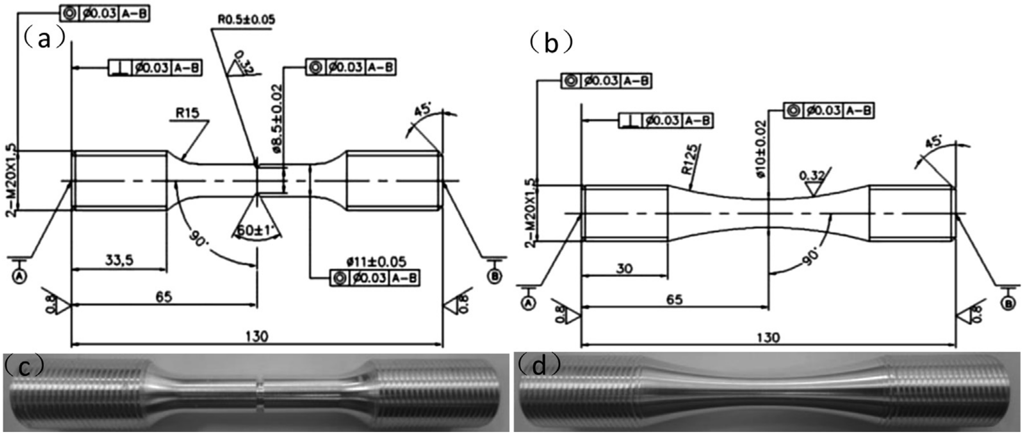

Fig. 1. The dimensions and digital picture of the high cycle fatigue specimens: (a, c) notched specimen ($\boldsymbol{K}_t = 3$), (b, d) smooth specimen ($\boldsymbol{K}_t = 1$).

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