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A critical discussion on influence of loading frequency on fatigue crack propagation behavior for extruded Mg–Al–Zn alloys

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ABSTRACT

Effect of loading frequency on the fatigue crack propagation (FCP) rate and mechanism of extruded Mg–Al–Zn alloys is discussed. The results demonstrate that the FCP rate of AZ80 and AZ61 alloys increases with reducing frequency. The frequency has a more significant influence on FCP rate of the AZ80 alloy than that of the AZ61 alloy. This scenario may be attributed to the thickness of the oxide films on the fracture surfaces, strain rate and the microstructure. A model based on the Langmuir and BET equation is established to predict the thickness of the oxidation films on the fracture surfaces.

1. Introduction

Mg alloys are increasingly used for light-weight constructions in transportation industry due to their high specific strength. For the applications as load-bearing components, it is necessary to evaluate various fatigue properties [1,2]. Mg alloys can be categorized into two kinds: cast and wrought alloys. The latter usually has mechanical properties superior to the former. The defects such as porosities and cavities with the varied shape and dimension, usually existing in the cast alloys, have a significant influence on the fatigue properties [3]. Whereas, wrought alloys are basically defect-free [4]. Therefore, it is of great interest to evaluate the fatigue properties and understand the intrinsic fatigue mechanism of Mg alloys based on the wrought ones instead of the cast ones.

Recently, studies on fatigue of the wrought Mg alloys AZ80 and AZ61 are focused due to their applications in automotive industries. Hilpert and Wagner [5] examined the fatigue performance of the extruded AZ80 alloy in ambient air as well as an aggressive environment created by a salt spray setup. The fatigue life reduced evidently in a corrosive environment. Shih et al. [6] studied the fatigue life of AZ61A (the second A-series number) and found that the crack initiated at subsurface or surface inclusions. However, the research on FCP of Mg alloys is sparsely found in literature [1]. A variety of factors such as environment, microstructure (i.e. texture), and heat treatment as well as loading parameters have remarkable impact on FCP rates of Mg alloys [2,5,7–9]. In addition, air seems to be an aggressive environment for Mg alloys [6,10,11]. Sajuri et al. [12] and the authors [13] investigated the effects of humidity and temperature on the fatigue life and the FCP of Mg alloy AZ61. They found that fatigue strength decreased significantly and FCP rate increased obviously with an increase in temperature, and both the fatigue strength and FCP rate are highly sensitive to the humidity levels present in the ambient environment. Therefore, load parameters such as load frequency may have crucial influence on the FCP rate of Mg alloys.

The previous studies indicate that the FCP rate of cast Mg alloy AZ91 increase with a reduction in frequency [14,15] in air. The authors' preliminary study also reveals that the influence of load frequency on FCP behavior of wrought Mg alloys AZ80 and AZ61 is noticeable [16,17]. However, there is ambiguous recognition about the intrinsic and extrinsic influence of the environment such as air and the relative humidity on FCP of Mg alloys. For instance, inert atmosphere (argon) or vacuum retards the FCP rate in comparison with the air. Dry oxygen accelerates the FCP rate of AM60 but decelerates the FCP rate of AZ91 [18,19], it is attributed to the thin film of Mg oxide retarding the FCP through closure effect [19]. But another explanation is that the brittleness of the oxide film does not contribute to the crack closure effects as much as it does in steel and aluminum alloys [18]. It is clear that the two statements are in a contradiction. Therefore, the effects of oxide film on the FCP mechanism of Mg alloys remain unclear. The

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present paper attempts to discuss the influences of frequency, oxide film and strain rate on FCP behavior of as-extruded Mg–Al–Zn alloys, and to clarify the FCP mechanism.

2. Experimental

The materials used are AZ80 (Mg–9.0 wt% Al–0.70 wt% Zn) and AZ61 (Mg–6.0 wt% Al–0.70 wt% Zn). The ultimate tensile strength, yield strength, elongation to failure for AZ80 and AZ61 are 333.0 MPa, 235.0 MPa, 7.0% and 274.0 MPa, 187.0 MPa, 21.2%, respectively [9,16]. Single-edge notched plate specimens were machined by electrodischarge machining (EDM) from the extruded sheets to the following dimensions: thickness of 8 mm, width of 32 mm, and length of 150 mm. The edge notch was machined by EDM to a length of 3.5 mm. A detailed illustration can be seen in Fig. 2 of Ref. [9]. The notch diameter is the size of the wire used with EDM. Constant load amplitude fatigue tests were performed using an EHF-EB10-20L servo-hydraulic fatigue machine in ambient air at 16–20 °C and 40–70% relative humidity (RH). A frequency range of 0–10 Hz, maximum load of 7 KN, and a load ratio of zero under a sinusoidal waveform were applied. The value of the crack length, a, was in situ measured by a traveling optical microscope (LDM, Questar), equipped with a graticule and rails enabling it to move horizontally or vertically. The oxide film and the fracture surface morphology were inspected via scanning electron microscope (SEM, Philips ESEM × L30 FEG) and X-ray photoelectron spectroscopy (XPS, LAS-3000), respectively.

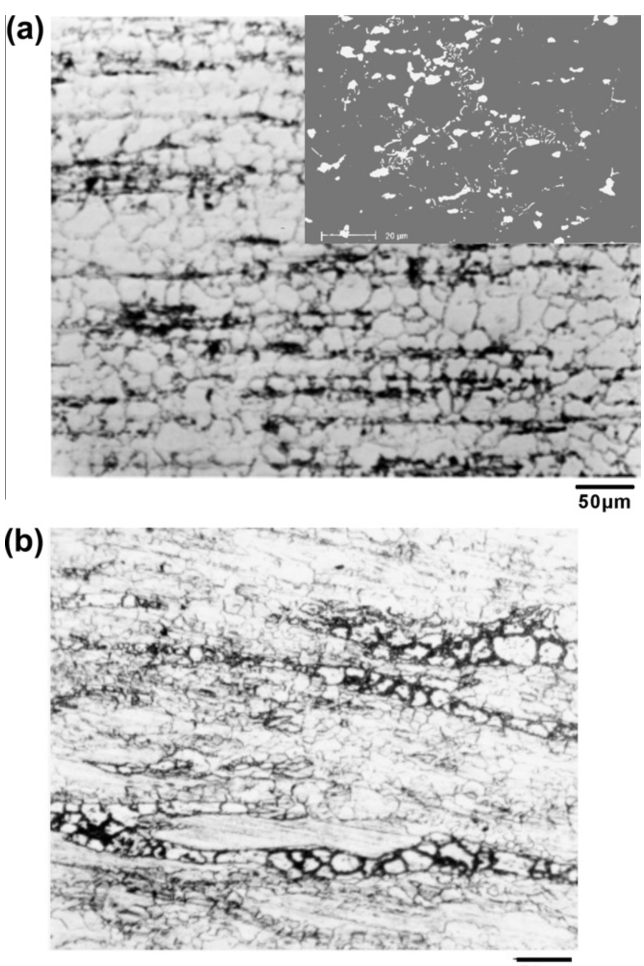

Fig. 1. Optical microstructure of (a) the AZ80 alloy, inserted the backscatter electron image of the β phase, and (b) the AZ61 alloy.

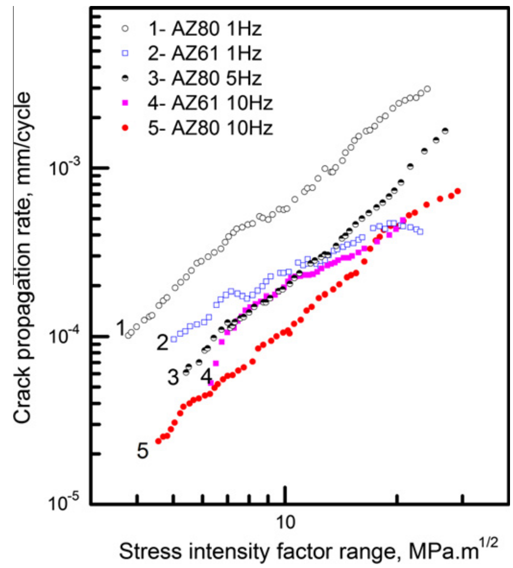

Fig. 2. Effect of frequency on the FCP rate of Mg alloys (a) AZ80 and (b) AZ61.

3. Results

The optical micrographs of microstructures in the extruded AZ80 and AZ61 alloys are presented in Fig. 1a and b, respectively. The microstructure (Fig. 1a) of the extruded AZ80 alloy with an average grain size of 17 μm is characterized by the presence of deformed bands with fine and equiaxed and recrystallized α grains, and β phases distributed along the grain boundaries as shown in the inserted backscatter electron image of SEM. The inhomogeneous microstructure of the AZ61 alloy is characterized by the presence of coarse and elongated α-grains and β phase and Mn-rich particles as well [16]. The average grain size of α-grains is approximately 18 μm (Fig. 1b), while the grain size of the extremely coarse grains is about 250 μm.

Fatigue crack propagation rate, da/dN, is typically plotted as log–log graphs of da/dN versus stress intensity factor range, ΔK. Fig. 2 exhibits the da/dN versus ΔK curves of the alloys AZ80 and AZ61 at various frequencies. It is obvious that frequency has a more significant influence on FCP rate of the extruded AZ80 alloy than the AZ61 alloy. The lower the frequency, the higher the FCP rate for each material. It is noticeable that the curves of the extruded AZ61 alloy exhibit a zigzag path indicating the crack advance and arrest. In particular, the crack route is more tortuous at 1 Hz than at 10 Hz. The reason for this variation may be concerned with both stochastic microstructure and oxidation of the fracture surfaces, while oxidation behavior is affected by loading frequency. Local differences in grain orientation, microscopic yield strength and grain boundary effects altered the local resistance to crack growth [20,21].

It is well known that the fatigue crack growth rate can be described by the Paris equation [22]:

$$\mathrm{d}a/\mathrm{d}N = C(\Delta K)^m \quad (1)$$

Constants m and C of the alloys at different frequencies are given in Table 1.

The fractographs of the AZ80 alloy at ΔK of 8.3 MPa m$^{-1/2}$ and 17.4 MPa m$^{-1/2}$ at frequencies of 5 Hz and 1 Hz are shown in

Table 1
m and C of the AZ80 alloy at various frequencies (R = 0).

Materials	f (Hz)	m	C	Materials	f (Hz)	m	C
AZ80	1	2.0	6.5×10^{-9}	AZ61	1	1.0	2.1×10^{-8}
AZ80	10	2.0	1.1×10^{-9}	AZ61	10	1.4	6.9×10^{-9}
AZ80	5	2.0	2.0×10^{-9}				