Materials Science and Engineering A 509 (2009) 1–7

Contents lists available at ScienceDirect

Materials Science and Engineering A

journal homepage: www.elsevier.com/locate/msea

Fatigue crack propagation behavior of an as-extruded magnesium alloy AZ80

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ARTICLE INFO

Article history:
Received 15 March 2008
Received in revised form
14 November 2008
Accepted 7 January 2009

Keywords:
Fatigue crack propagation
Magnesium alloy
Frequency
Load ratio
Oxide film
Crack closure

ABSTRACT

An investigation of the fatigue crack propagation (FCP) behavior of the as-extruded magnesium alloy AZ80 was made by means of the constant load amplitude fatigue test, scanning electron microscope (SEM), transmission electron microscopy (TEM) and Auger electron spectroscopy (AES). The results demonstrated that loading frequency had a significant influence on fatigue crack propagation rate, and it increased with a decrease in loading frequency and an increase in load ratio. Crack closure induced by plasticity rather than oxide film might play a predominant role in fatigue crack propagation. The coalescence of the microvoids was proposed to be the mechanism of fatigue crack propagation of the extruded magnesium alloy AZ80.

1. Introduction

Magnesium alloys are potential structural materials in the automobile industries due to their high specific strength and mankind's environmental requirement for reduction in air pollution. In spite of the presently most utilized static parts such as cases, housings, brackets, panels etc., the wrought magnesium alloys have attracted attention for scientists and engineers because of their superior mechanical properties to the cast ones [1–3]. The extruded magnesium alloy AZ80 will probably be a broader consuming material in automotive and other strategical applications. Therefore, it is of primary importance to understand the fatigue crack propagation (FCP) behavior of the wrought magnesium alloys.

The FCP rate at the low stress intensity is sensitive to microstructure, load ratio and environment [4]. Researches [5,6] have shown that crack closure (plasticity, oxide and roughness-induced) plays a crucial role in near threshold crack growth in the magnesium alloys. At the low stress intensity, crack opening displacement (COD) is relatively small. Hence, any oxide debris or micro structural feature (roughness) with a size comparable to the COD will promote early contact of the crack surfaces and then result in crack closure. Kobayashi et al. [5] suggested that the influence of load ratio for AZ91D on the FCP velocity could be associated with the effect of the crack closure as well as the property of the oxide films produced on the fresh surfaces. While Liu et al. [6] claimed that plasticity induced crack closure may play a predominant role in fatigue crack propagation.

The previous studies [7,8] indicated that the initial film immediately formed on pure magnesium after exposing to the fresh surface produced by scratching in air. Research showed that in low humidity atmosphere, no further increase in film thickness was observed. The initial oxide is a mixture of Mg, MgO and 50–60 wt% $Mg(OH)_2$. As for the Mg–Al alloys, their oxide films were largely enriched in Al in air, especially for the alloys containing more than 4% Al [9,10]. When exposed to humid air, the film thickness was much greater than that in dry air and it exhibited a duplex structure: the 20–40 nm thick outer layer was relatively compact and amorphous, and the inner layer was hydrated and cellular [8].

Some researches [5,6,11] have shown that the loading frequency for cast magnesium alloy AZ91 and as-extruded AZ61 alloy had significant influence on FCP speeds. Unfortunately, the FCP behavior of magnesium alloys has not been well-understood yet. The objective of the paper is to investigate the effect of testing parameters (e.g., loading frequency and load ratio), and have a further insight into FCP mechanism of the extruded AZ80 alloy.

2. Experimental

Single-edge notched plate specimens (shown in Fig. 1) were machined from the extruded sheets of magnesium alloy AZ80 (Mg–9.0% Al–0.7% Zn). The ultimate tensile strength and yield strength of the alloy are 333 MPa and 235 MPa, respectively. The samples were machined from the as-received alloys on three directions: longitudinal (L), long transverse (T), and short transverse (S)

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doi:10.1016/j.msea.2009.01.013

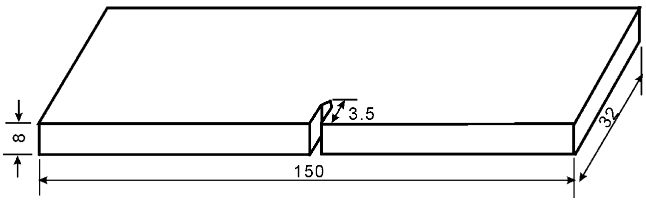

Fig. 1. The size and shape of the fatigue test samples.

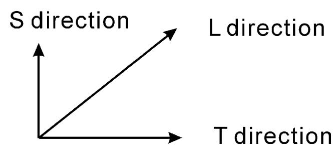

Fig. 2. Schematic representation of the three-dimensional directions: longitudinal (L), long transverse (T), and short transverse (S) direction for the samples' machining.

direction (shown in Fig. 2). Samples were polished with fine grit emery papers, followed by disc polishing with 1 μm diamond powder, etched in a 5% nitric acid ethanol solution. Microstructure and fracture surfaces were examined by using optical microscope and Philips ESEM×L30 FEG SEM, respectively.

Constant load amplitude static fatigue tests were performed on an EHF-EB10-20L servo-hydraulic fatigue machine in air at room temperature: 16–20 °C, relative humidity (RH): 40–70%. 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 crack length a was measured with a traveling long distance microscope, and stress intensity factor range ΔK was calculated according to ASTM standard E647.

The microstructure morphology at the crack tip was observed by virtue of JEM-2000FXII type TEM. The foils for TEM were cut from the crack tip of the fatigued specimens which were performed at Paris stage at two different parts, $\Delta K = 7\,\mathrm{MPa\,m^{1/2}}$, $24\,\mathrm{MPa\,m^{1/2}}$, respectively. The foils were first polished by hands with 1000 SiC papers to approximately 100 μm thickness and then thinned by argon ions.

The oxide film thickness was measured by means of an Auger electron spectroscopy (AES). A part from the longitudinal surface was taken as the blank sample (designated as sample 0), which was polished just before the fatigue test in order to get a reference of oxide thickness at the same time as possible. Due to the size limitation of samples for AES, the fractured sample was cut into three parts (shown in Fig. 3): part I (region I), part II (region II), and part III (region III), corresponding to sample 1, sample 2, and sample 3, respectively, once the fatigue test finished. After that they were cleaned with acetone agent, and were put into a desiccating glass vessel.

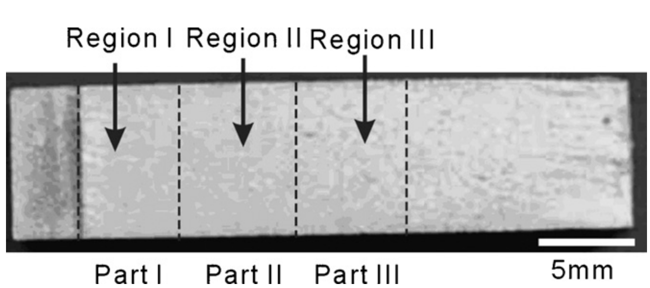

Fig. 3. Fracture divided into three parts, corresponding to various regions.

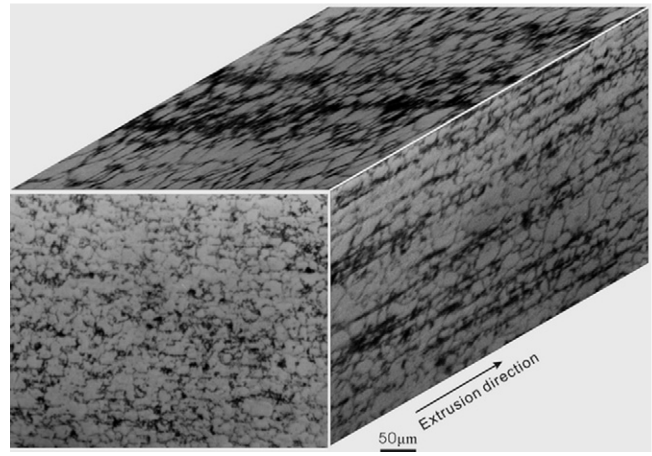

Fig. 4. Three-dimensional optical microstructure of as-extruded magnesium alloy AZ80.

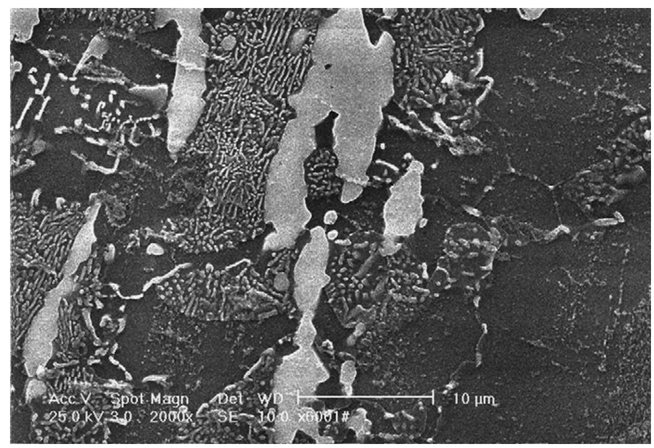

Fig. 5. SEM images of microstructure of as-extruded magnesium alloy AZ80.

3. Results and discussions

3.1. Microstructure

The three-dimensional optical photomicrograph of microstructure of the as-extruded AZ80 is presented in Fig. 4. The microstructure is characterized by the extended deformation bands with fine and equiaxed recrystallized grain α matrix and β phases distributing along the grain boundaries; the averaged grain size is approximately 17 μm measured by the linear intercept method. From Fig. 5, the primary elongated bulk β compounds and discontinuous lamellar β phases are visible.

3.2. Fatigue crack propagation

Fatigue crack propagation rate is typically plotted as log–log graphs of da/dN versus ΔK. The da/dN versus ΔK curves of the AZ80 alloy is shown in Fig. 6. It shows that frequency has a signifi-

Table 1
The values of constants m and C of as-extruded magnesium alloy AZ80 at different frequency and load ratio.

Materials	R	f [Hz]	m	C
AZ80	0	1	2.0	6.5×10^{-9}
AZ80	0	5	2.0	2.0×10^{-9}
AZ80	0	10	2.0	1.1×10^{-9}
AZ80	0.5	5	2.0	8.4×10^{-9}