Low-cycle fatigue behavior of two magnesium alloys

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Magnesium alloys possess many excellent performances, such as low density, high specific strength, excellent thermal conductivity, and machinability. Magnesium alloys, including Mg-Al alloy family, are increasingly considered for structural components, especially in automotive industry. AZ91 alloy with about 9 wt.% Al and 1 wt.% Zn is the most common magnesium die-casting alloy. It has excellent castability and good room-temperature mechanical properties. AE42 alloy with about 4 wt.% Al and 2.5 wt.% rare earth elements shows good creep resistance to 150 °C, and is often used for automotive engine components. For both AZ91 and AE42 alloys, few low-cycle fatigue data are available even though their monotonic tensile and creep properties have been well documented [1–6].

In this paper, the low-cycle fatigue behavior of two magnesium alloys including AZ91 and AE42 were investigated. The rectangular fatigue samples with dimensions 14 × 5 × 5 mm in gauge section were directly machined from die-cast plate of each alloy (designated F). Some fatigue samples were subjected to solution treatment in argon at 415 °C for 12 hr (designated T4). Fully-reversed pull-push fatigue tests were performed at room temperature in laboratory air under total strain amplitude control mode using Shimadzu servohydraulic testing machine. All tests were run to final separation of sample, and the corresponding cycling number was defined as low-cycle fatigue life.

The fatigue life data (total strain amplitude, $\Delta\varepsilon_t/2$, versus number of cycles to failure, N_f) of two alloys with F and T4 status are shown in Fig. 1a and b, respectively. It can be seen that at most of total strain amplitudes except for the lowest strain amplitude of 0.3%, the AZ91-T4 alloy gives greater resistance on strain cycling than the die-cast AZ91 alloy. On the other hand, the AE42 alloy subjected to solution treatment exhibits longer fatigue life than the die-cast AE42 alloy at all total strain amplitudes imposed in this investigation. The above-mentioned fact implies that solution treatment can effectively enhance the resistance to fatigue damage of some Mg-Al alloys.

For total strain amplitude controlled fatigue tests, the imposed total strain amplitude can generally be divided into the elastic strain amplitude ($\Delta\varepsilon_e/2$) and plastic strain amplitude ($\Delta\varepsilon_p/2$). The empirical relationship between elastic strain and the number of reversals to failure ($2N_f$) is usually described by Basquin equation

$$\Delta\varepsilon_e/2 = \frac{\sigma_f'}{E}(2N_f)^{-b} \quad (1)$$

where σ_f' and b are the cyclic strength coefficient and exponent, respectively, and E is the modulus of elasticity. The elastic strain amplitude-reversals to failure curves of two alloys are given in Figs 2 and3, where the value of the elastic strain amplitude is taken from the half-life hysteresis loops. It is obvious that for both alloys, the elastic strain amplitude and fatigue life data can be correlated by Basquin law. Through the apparent linear fit, the strain fatigue parameters σ_f' and b for two alloys are determined and listed in Table I. It is found that the values of σ_f' and b in the AZ91-T4 alloys are close to those of the die-cast AZ91 alloy. However, the AE42 alloy subjected to solution treatment shows the higher value of σ_f' and b than the die-cast AE42 alloy.

It is well known that as a measurable physical parameter during total strain amplitude controlled cyclic deformation, cyclic plastic strain results in a number of damage processes which affect the microstructure and strain fatigue life. In general, the dependence of reversals to failure on the plastic strain amplitude is represented by the Coffin-Manson equation, i.e.

$$\Delta\varepsilon_p/2 = \varepsilon_f'(2N_f)^{-c} \quad (2)$$

where ε_f' and c represents the cyclic ductility coefficient and exponent, respectively. For two magnesium alloys at different processing conditions, the Coffin-Manson curves are shown in Figs 2 and 3, where the value of plastic strain amplitude is taken at half life.

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TABLE I The strain fatigue parameters of two alloys

Alloy	Processing condition	σ'_f (MPa)	b	ε'_f (%)	c	N_T	Comments
AZ91	F	480.7	0.141	2.4	0.365	19	($\Delta\varepsilon_t/2 \geq 0.7\%$)
	T4	491.9	0.137	1.5	0.209	54	($\Delta\varepsilon_t/2 < 0.7\%$)
				350	0.943		
AE42	F	1128.9	0.225	6.6	0.473	24	
	T4	1508.8	0.331	7.4	0.570	14	

It can be noted that for the AE42 alloy with T4 and F status as well as the die-cast AZ91 alloy, the Coffin-Manson equation can well describe the relationship between the plastic stain amplitude and reversals to failure throughout the whole total strain amplitude examined in this investigation. For the AZ91-T4 alloy, however, the Coffin-Manson curve exhibits a bilinear behavior with a change of slope occurring at the plastic strain amplitude of about 0.3% (the corresponding total strain amplitude

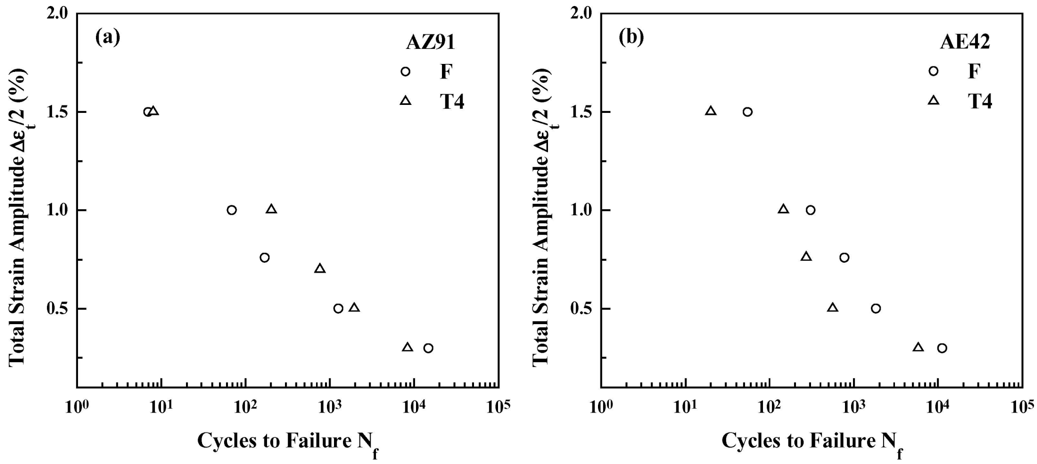

Figure 1 Total strain amplitude as a function of cycles to failure for two alloys under different processing conditions: (a) AZ91 and (b) AE42.

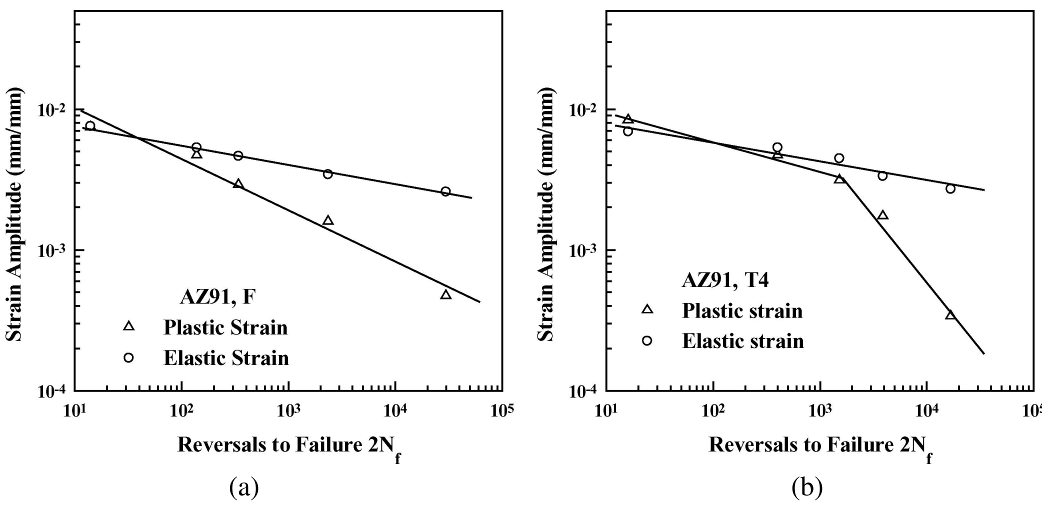

Figure 2 Plastic and elastic strain amplitudes versus reversals to failure for AZ91 alloy with different processing conditions: (a) F and (b) T4.

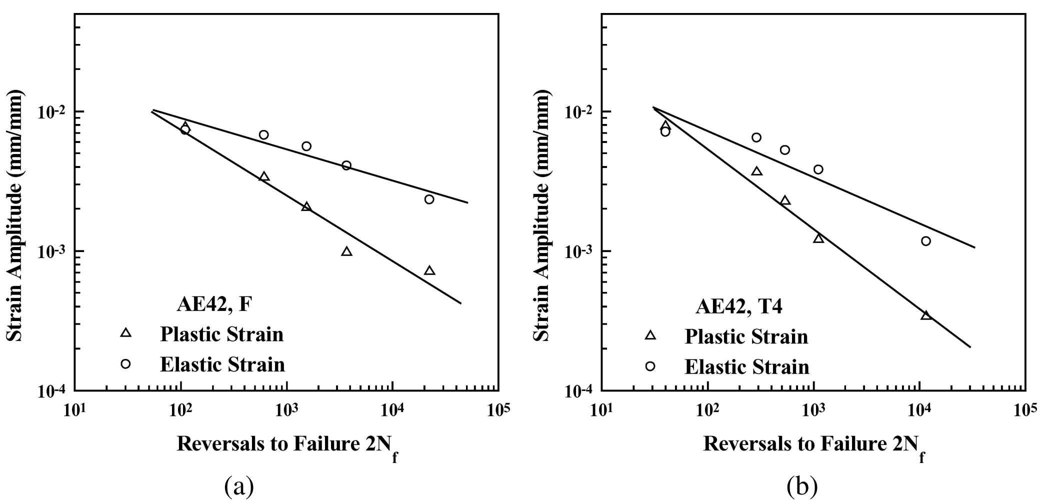

Figure 3 Plastic and elastic strain amplitudes versus reversals to failure for AE42 alloy with different processing conditions: (a) F and (b) T4.

is 0.7%). In fact, a break or bilinearity in the Coffin-Manson curve had also been observed in other materials including superalloys [7] and dual-phase steels [8]. These authors suggested that the change in deformation mechanism or fracture mode led to the occurrence of bilinear behavior in these materials. It may be expected that for the AZ91-T4 alloy, the evolution in microstructure induced by strain cycling should be related to the break in the Coffin-Manson curve. By the apparent linear fit, the value of $\varepsilon'_{\mathrm{f}}$ and c for two alloys are obtained and given in Table I. It can be noted that the AE42 alloy subjected to the solution treatment shows the higher values of $\varepsilon'_{\mathrm{f}}$ and c.

In addition, the transition fatigue life, N_{T} (the corresponding number of cycles when $\Delta\varepsilon_{\mathrm{e}}/2 = \Delta\varepsilon_{\mathrm{p}}/2$), for two alloys with different processing conditions has been also determined. The corresponding values of N_T are also given in Table I. It can be noted that the transition fatigue life of two alloys is considerably low, which can be attributed to the low ductility of these magnesium alloys. The above fact also means that the fatigue failure of the material tends to be controlled mainly by elastic deformation in the total strain ranges investigated. For the AZ91 alloy, the transition fatigue life significantly increases due to solution treatment. However, the transition fatigue life of the AE42-T4 alloy is slightly lower than that of the die-cast AE42 alloy.

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