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# Effect of aging treatment on low-cycle fatigue behavior of extruded Mg–8Al–0.5Zn alloys

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ABSTRACT

The low-cycle fatigue properties of Mg–8Al–0.5Zn (AZ80) magnesium alloy have been studied as a function of precipitation state. It has been shown that the presence of precipitates significantly reduces tension–compression yield asymmetry, compared with solution treated material. This decreased asymmetry significantly reduces tensile mean stress during low-cycle fatigue process. As the cyclic deformation progressed, an abrupt increase in the plastic strain amplitude prior to failure is observed, representing the onset of fatigue crack initiation. This increase disappears in the aged sample, which leads to the significantly decreased area of crack propagation zone, and shorter lifetime. Due to the enlarged reverse plastic zone size, the aged sample showed microscopically rough faceted fracture surfaces in the fatigue crack propagation zone.



## 1. Introduction

Magnesium (Mg) alloys have excellent properties, such as light weight, high specific strength and stiffness, machinability and recyclability. These advantages make it very attractive for the transportation industry, in particular, as components in aeroplanes or ground vehicles for which weight saving is extremely important [1]. As structural materials in service, magnesium alloys are usually subjected to the cyclic deformation leading to catastrophic fracture after certain period of time. Therefore, the cyclic deformation behavior of these materials needs to be further investigated for safety reasons.

Mg alloys can be categorized into two kinds: cast and wrought alloys. Currently, the majority of structural parts made of magnesium alloys is cast ones because of their high productivity and complex shape. However, casting defects, such as casting porosity and cavity [2], made the structural component's mechanical properties impaired, especially for the fatigue resistance. Whereas, wrought magnesium alloys can avoid the casting defects. 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.

Most magnesium alloys are with hexagonal close packed (HCP) crystal structure and they have very limited number of slip systems at room temperature. Besides slip, twinning is another important plastic deformation mode in magnesium alloys. For HCP magnesium with a $c/a$ ratio of approximately 1.622, tensile twinning on the $\{10\bar{1}2\}$ plane is activated by a compressive stress parallel to the basal plane or a tensile stress perpendicular to the basal plane [3]. The polar nature of tensile twinning is the reason for the well-known tension–compression strength asymmetry of wrought magnesium alloys. Such a difference in yield strength causes the tensile mean stresses during low-cycle fatigue process [4]. It is well known that tensile mean stress has a harmful effect on the fatigue resistance by accelerating crack initiation and propagation mechanisms, while the reverse is true for compressive means stress [5]. Therefore, this yield asymmetry is generally considered to be a detrimental property.

One means by which this asymmetry can be attenuated is by the use of precipitation particles to modify the process of twinning in aged magnesium alloys [6–9]. The interaction between twinning and precipitates has been proposed to primarily arise from the difficulty experienced by migrating twin boundaries in propagating through a high density of precipitates [7]. Recently, Standford and Barnett [6] have found reductions in twin size and total twin volume fraction in an aged binary Mg–5%Zn alloy. As such, the variation in twinning behavior by precipitates was helpful to decrease the yield asymmetry. Although some investigators have reported that precipitates lower the crack growth resistance in extruded magnesium alloy AZ80 [1,10], the effect of precipitates on fatigue behavior is not clear in strain-controlled fatigue. The main objective of this investigation was to evaluate the strain-controlled low-cycle fatigue behavior of an extruded AZ80 alloy with and without precipitates.

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## 2. Experimental procedures

The starting material for this study was an extruded rod of commercial AZ80 (Mg–8wt.%Al–0.5wt.%Zn) alloy. Extrusion was carried out at about 400 °C in a container with an extrusion ratio of 7 and a final diameter of 30 mm. The extruded specimens were first solution treated at 415 °C for 12 h followed by water quenching, and then aged at 200 °C for 21 h.

All tests were conducted using an Instron-8801 testing machine in air at room temperature. Tension ($2 \times 3 \times 10\ mm^3$) and compression ($5 \times 5 \times 8\ mm^3$) specimens were machined from the extruded rod. The initial strain rate was $5 \times 10^{-4}$/s. A dog-bone sample for low-cycle fatigue tests, measuring 14 mm in gauge length, 6 mm in gauge width, and 5 mm in thickness was cut from the rod along extrusion direction according to ASTM E606 [11]. The cyclic frequency was 1 Hz. Before testing, the samples were polished with 2000 grit silicon carbide abrasive paper, followed by electropolishing using a solution comprising 15 ml $HClO_4$, 50 ml glycol and 180 ml ethanol to eliminate the residual stress of the surface layer. Microstructures were examined with an optical microscope and a Quanta-200 scanning electron microscope.

## 3. Results and discussion

### 3.1. Microstructure

Fig. 1a and b shows the microstructures of the solution treated and aged AZ80 alloy, respectively, on the cross-section parallel to the extrusion direction. The average grain size of the solution treated sample is about 32 μm and no twin was found in grains before loading. After aging, the microstructure is characterized by the presence of intermetallic compounds $Mg_{17}Al_{12}$ at the grain boundaries and within grains [1].

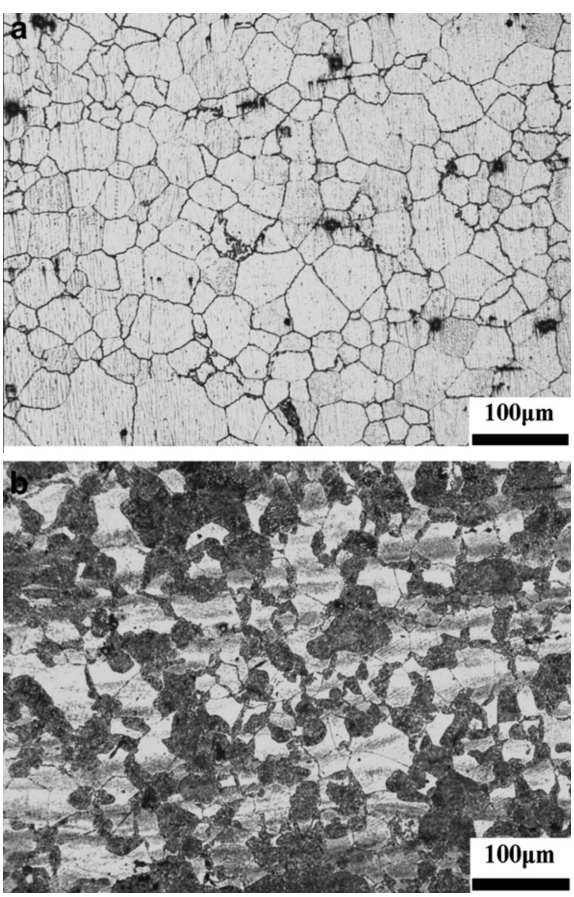


**Fig. 1.** Optical microstructures of AZ80: (a) solution-treated condition, (b) aged condition.

### 3.2. Monotonic stress–strain behavior

The tension–compression asymmetry described above is clearly illustrated in the tensile and compressive engineering stress–strain curves for the solution treated AZ80 alloy (Fig. 2). Both the yield strength and the work hardening rate showed a marked asymmetry. The ratio of compressive to tensile yield strength (denoted the asymmetry ratio here) was about 0.6. This phenomenon has been attributed to the mechanical twinning on the $\{10\bar{1}2\}$ planes along the $< 10\bar{1}1 >$ directions during compression along the extrusion direction but not during tension along the same direction [3]. This is primarily the result of extrusion texture, where a significant fraction of grains orientated with their basal planes paralleling to the extrusion direction, and the polar nature of twinning [3]. Also, the AZ80 alloy showed the parabolic hardening of slip-dominated deformation in tension, whereas it showed the sigmoidal (S-shaped) hardening of twin-dominated deformation in compression.

Also shown in Fig. 2 are the tensile and compressive stress–strain curves for the aged alloy. In this state, the asymmetry ratio was about 0.8, indicating the difference between tension and compression yield strength decreased significantly. And both the tensile and compressive yield strengths were enhanced obviously, compared with those of the solution-treated ones.

### 3.3. Fatigue properties

Fig. 3 presents the cyclic deformation responses of the solution treated and aged samples deformed with a strain amplitude of 0.4%. Apparently, there is an obvious cyclic hardening behavior occurred for the solution treated sample, while the aged alloy is characterized by cyclic softening. Within the initial few cycles, the cyclic stresses of the aged samples are always higher than those of the solution treated samples. This can be explained by the tensile strength of the aged samples being higher than that of the solution treated samples. However, as the cyclic deformation proceeded, the cyclic stresses of the solution treated samples are higher than those of the aged samples. In addition, the fatigue life is longer for the solution treated alloy.

Representative hysteresis curves are shown in Fig. 4 for solution-treated and aged samples at total strain amplitude of 0.4%. In the first cycle, the hysteresis loop of the aged sample is symmetric between the compression and tension cycle, which are usually

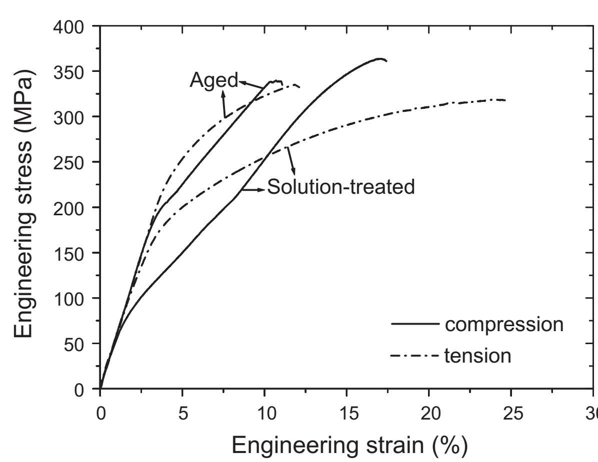


**Fig. 2.** The engineering stress–strain response of solution treated and aged AZ80 alloy tested in tension and compression.