INFLUENCE OF AGING ON LOW CYCLE FATIGUE BEHAVIOR IN 8090 Al-Li ALLOY[①]

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ABSTRACT Low cycle fatigue (LCF) tests under different total strain amplitudes have been conducted in four aging conditions of 8090 Al-Li alloy. It was found that the cyclic stress response and the LCF lifetime of the alloy varied with the aging conditions and strain amplitudes. The cyclic stress-strain behaviour and fracture mode of Al-Li alloy are closely related to an increasing in the dislocation density, dislocation-dislocation interactions and interactions between the precipitates with dislocations.

Key words: low cycle fatigue cyclic hardening precipilate phase

1 INTRODUCTION

Al-Li alloys represent a new class of weight, high modulus, high strength, economical structural materials. Therefore, these alloys are specially attractive to aeronuatical and aerospace industries.

Fatigue fracture of materials accounts for the majority of in-service failure in engineering components and low cycle fatigue behaviour are important for lifetime prediction in applies alloys. Several researchers stated[1-6] that during low cycle straining Al-Li alloys in general, initially harden at plastic strain amplitudes less than $\sim 10^{-3}$, followed by saturation before softning to final fracture. At higher plastic strain ($\Delta\varepsilon_p/2 > 10^{-3}$), however, the alloys continuouslly soften to failure with little cyclic stability. Therefore, it is believed that interaction between deformations and microstractures during fatigue loading will result in significant effects on resistances to fatigue and lifetime of the alloys.

The aim of the preset study is to clarify the influence of microstractural factors on the cyclic deformation behaviors in 8090 Al-Li alloy, such as, the size and distribution of δ', the dislocation configurations and the interactions of δ' phase with dislocations.

2 MATERIALS AND EXPERIMENTAL PROCEDUCES

The 8090 Al-Li alloy used in this study has a chemical composition (wt.-%) of 2.5Li, 1.44Cu, 1.18Mg, 0.15Zr, <0.3Fe, <0.2Si and the balance of Al. The alloy was smelted by vacuum induction heating in a graphite crucible. The as-cast ingots were homogenized and extruded into bars with a diamter of 16 mm.

All samples were solutionized at 530 ℃ for 0.5 h and then cold water quenched. Part of the samples were kept at room temperature for more than 30 days and others were aged for 16 h at 170 ℃, 190 ℃ and 210 ℃, repectively.

Fully reversed LCF tests were conducted under total strain control with a triangular

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waveform and a constant strain rate of $3\times10^{-3}S^{-1}$ on a Mayes machine.

The foils of different specimens were examined with a Philips EM420 TEM.

3 EXPERIMENTAL RESULTS AND DISCUSSION

The cyclic response curves of 8090 alloy in different aging conditions are shown in Fig. 1. It is interesting to note that the materials in all aging conditions cyclically harden at first and the higher the strain amplitude, the greater the amount of hardening. At higher strain amplitudes ($\Delta\varepsilon_t/2 >= 0.5\%$); the specimens in natureaged exhibit a continuous hardening, then softening until final fracture (Fig. 1a). At lower strain amplitude ($\Delta\varepsilon_t/2 = 0.3\%$), it in natureaged is cyclic hardening, followed by saturation before softening to final failure. However, for under-and peakaged when high strain amplitude ($\Delta\varepsilon_t/2 = 0.7\%$) is applied, cyclic hardening occurs continuously until failure without cyclic stability; at middle strain amplitude ($\Delta\varepsilon_t/2 = 0.5\%$), cyclic stress responses show hardening at the first cycle, then rapidly softening in several cycles to saturation with longer plateau region until final fracture; when lower strain amplitude ($\Delta\varepsilon_t/2 = 0.3\%$) is applied, materials harden initially and then saturate fastly until failure (Fig. 1(b)). For overaged microstructure when strain amplitudes are higher than 0.3%, it similars to behavior at high strain amplitude in under-and peakaged; when strain amplitude is equal to 0.3%, it is consistent with middle strain amplitude results in under-and peakaged.

At an equivalent strain amplitude, the LCF life of the naturally aged alloy is the longest and the LCF property in under-and peakaged is similer to each other, but the overaged specimen exhibits the lowest fatigue lifetime and the inferior response stress during fatigue loading. The low cyclic fatigue response stresses in natureaged are lower than that in under-and peakaged at the same strain amplitude.

The variation in flow stresses during cyclic loading can be predominantly attributed to the increase in dislocation density, dislocation-dislocation interactions and interactions of dislocations with precipitates in the alloy. For all aging conditions at low strain amplitude materials are rapidly hardening to saturation and cyclic response stresses are lower than that at higher strain amplitude. Because the limited slip systems are activated at low

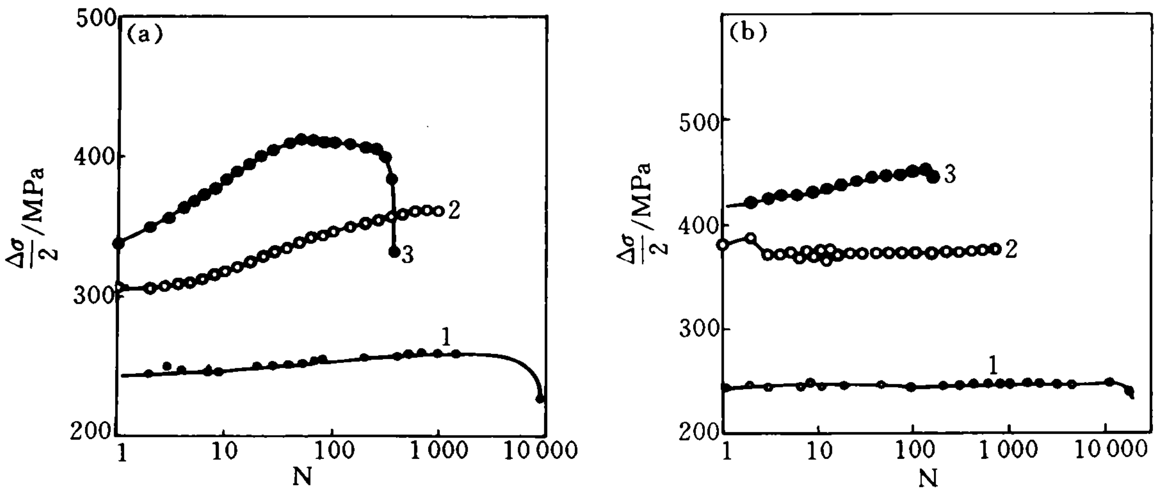

Fig. 1 Stress response to cyclic loading(N) of a Al-Li in the nature (a) and peakaged (b)

1—0.3% total strain; 2—0.5% total strain; 3—0.7% total strain

strain amplitude, mobile dislocations are minor, the distance of dislocation motion is shorter. Therefore, dislocation density is lower and dislocations preferentially concentrate near grain or subgrain boundaries (Fig. 2a). When higher strain amplitudes ($\Delta\varepsilon_t/2 = 0.5\%$) are applied the persistant hardening is believed to result from the continuous multiplication of dislocations and the pile-up of dislocations at grain or phase boundaries, but the softening may be attributed to the shearing of precipitates. Consequently, with increasing strain amplitudes, the dislocation density increases, especially dislocation-dislocation interactions and the interactions of dislocations with precipitate particles become significant. Dislocation tangles occur and dislocations are more homogenously distributed (Fig. 2 (b)). At higher strain amplitudes, the particles in slip bands are clearly sheared. It is completely congruously with result which is reported by Xu[7].

Effect of aging on the LCF resistance in Al-Li alloys can be essentially attributed to the interactions of dislocation with strengthening precipitates. The strong cyclic hardening behavior of 8090 alloy is closely related to volume fraction and size of δ'. The sizes of δ' are found to be in the order of 0.005, 0.020, 0.025 and 0.050 nm in nature-under-peak-and overaged condition, respectively.

Observation of SEM and TEM revealed that at low strain amplitude slip is planar; microcracks nucleated along slip band intrusions emerging on the surface and crack propagation occurs initially by transgranular mode. The fracture modes either in the crack initiation or propagation regions are found to be mixed at the intermediate strain amplitude. When the applied strain amplitude becomes higher, the fracture is characteriged by intergranular modes because cracks initiate and growth along grain boundaries at which slip bands impinge (Fig. 3).

Except overaged alloy in all microstructures, planar slip due to shearing results in strain localization along slip band and lead to slip band cracking. In overaged material at all strain amplitudes, because of coarsening of particles and widening of the precipitation free zone (PFZs) at grain boundaries, particular, strain localization in PFZs may cause grain boundaries cracking and promote intergranular fracture.

4 CONCLUSIONS

(1) The 8090 Al-Li alloy of all aging conditions hardens initially in LCF and the higher the strain amplitude, the greater the amount of hardening in the same aging conditions.

(2) The cyclic stress response of the 8090

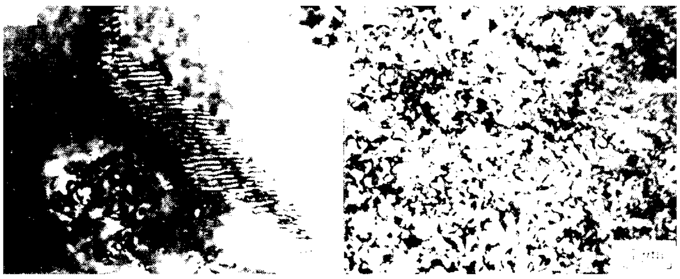

Fig. 2 TME bright field micrographs showing dislocation structures in peakaged at 0.3% (a) and 0.7% (b) strain amplitudes

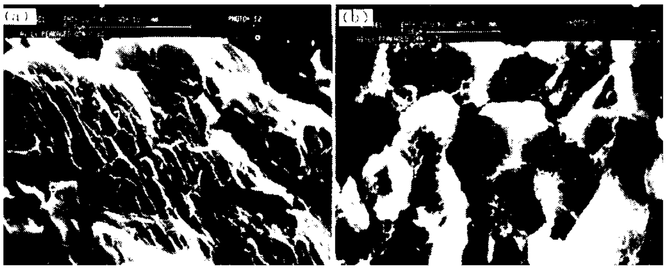

Fig. 3 SEM micrographs showing fracture modes in peakaged at 0.3% (a) and 0.7 (b) strain amplitudes

Al-Li alloy varied with the aging conditions and strain amplitudes. The only specimens in natureaged exhibit clearly softening characteristic after hardening at higher strain amplitudes($\Delta\varepsilon_t/2 >= 0.5\%$).

(3) At an equivalent strain amplitude, the LCF lifetime of 8090 Al-Li in natureaged is the longest, then overaged microstructure exhibits the lowest fatigue life and the inferior response stress. the LCF behavior in under- and peakaged is similar to each other during fatigue loading.

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