Materials Science and Engineering A 528 (2011) 2017–2022

Contents lists available at ScienceDirect

Materials Science and Engineering A

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

The behavior of fatigue crack initiation and propagation in AA2524-T34 alloy

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ARTICLE INFO

Article history:
Received 9 March 2010
Received in revised form 23 October 2010
Accepted 26 October 2010

Keywords:
Aluminum alloys
Fatigue crack initiation
Micro-crack propagation

ABSTRACT

With the help of a four-point-bend fatigue rig, high-cycle fatigue tests were carried out on an AA2524 Al alloy at room temperature, 15 Hz and $R = -0.1$ in ambient air. Optical microscopy (OM) and scanning electron microscopy (SEM) were employed to capture a detailed view of the fatigue crack initiation and propagation of the samples as well. The fatigue strength is 70 pct of their yield strength. Fatigue cracks were found to be always initiated from the second phase particles or the interface between the second phase particles and matrix. And grain orientation may be the key factor controlling the micro-crack deflection.

1. Introduction

Owing to their high strength and low density, the Al–Cu–Mg based 2000 series aluminum alloys, such as 2024, are widely used for constitutive parts of aircrafts and thus damage tolerance is a critical issue in aeronautics [1–3]. New generation aluminum alloys are developed to improve their specific properties including damage tolerance through optimization of microstructures to replace conventional AA2024 alloy. Therefore, AA2524 alloy was developed by Aluminum Company of American (AlCOA) in the 1990s via adjusting the Cu and Mg alloying elements and reducing Fe and Si levels [4].

Fatigue properties of the Al–Cu–Mg based AA2024 alloys has been extensively studied, with special emphasis on the correlation of microstructure (constituent particles [5–7], grain structure [8], texture [8,9], strengthening precipitates [8,10,11]) to the initiation and growth of fatigue cracks. Several papers published have discussed the fatigue performance of AA2524 alloy. Srivatsan et al. [3,12] studied the influence of test temperature on high-cycle fatigue properties and fracture characteristics of AA2524 alloy. It was found that the increase in test temperature had a detrimental influence on cyclic fatigue life of specimens taken from both the longitudinal and transverse orientations of the wrought plate. P.J. Goden et al. compared the resistance to the onset of multi-site damage in thin 2024-T3 and 2524-T3 sheet [13]. However, the fatigue properties critical to engineering design, such as the fatigue strength, crack initiation, micro-crack propagation, of AA2524 alloys have not been investigated extensively. In this work, we used four-point-bend apparatus to obtain fatigue data for AA2524-T34 alloy and described the experimental investigations performed to study the crack initiation and micro-crack propagation behavior of the alloy.

2. Materials and experimental details

The AA2524 Al alloy used for this work was provided by ALCOA with the chemical composition shown in Table 1. The as-received condition was solution heat treated, water quenched, stretched by 4 pct, and naturally aged (T34). The tensile yield strength of the alloy was 360 MPa.

The four-point-bend test provides a great deal of excellent features in studying the crack initiation and propagation [14,15]. Therefore, it was used to gauge the fatigue properties of the AA 2524 alloy. Samples for the tests were cut from the AA 2524-T34 sheet, parallel to the L-T plane (L, rolling direction and T, long transverse direction) with their loading direction aligned with L. The test geometry was shown in Fig. 1(a) and the schematic diagram of the installation method of four-point-bend fatigue test was illustrated in Fig. 1(b). Before fatigue tests the polishing was carried out on the surfaces of the samples that were loaded in tension during the test using waterproof SiC polishing papers followed by mechanically polished using a silica colloidal liquid. The fatigue tests with a stress radio (R, $R = \sigma_{min}/\sigma_{max}$) of −0.1 were conducted at a frequency of 15 Hz, with a waveform and at room temperature in laboratory air of which the humidity was maintained at about RH 15 pct. Fatigue tests were periodically interrupted for observation and measurement of cracks. After failure, scanning electron microscopy (SEM) with energy-dispersive spectroscopy (EDS) was used to investigate

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doi:10.1016/j.msea.2010.10.085

Table 1
Chemical composition of the AA2524 Al alloy (wt%).

Alloys	Si	Fe	Cu	Mn	Mg	Zn	Al
AA2524	0.04	0.08	4.3	0.578	1.4	0.008	Balance

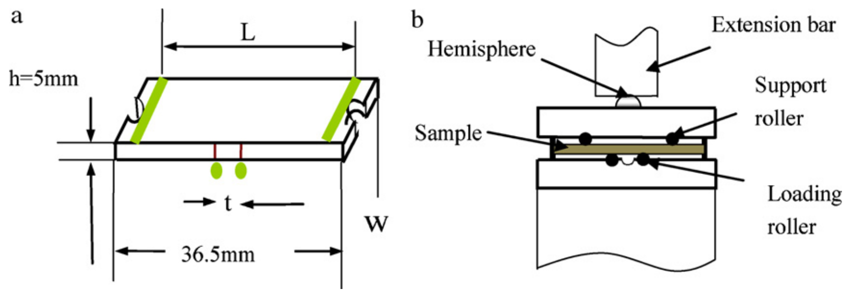

Fig. 1. Schematic diagrams showing the sample size and method of installation (a) sample dimensions and testing geometry and (b) the method of installation.

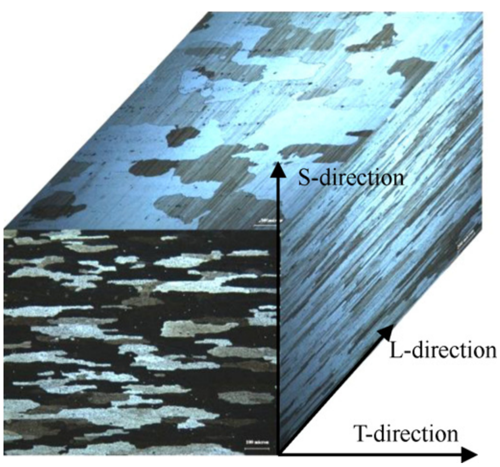

Fig. 2. Optical micrographs of grain structure of AA2524-T34 alloy.

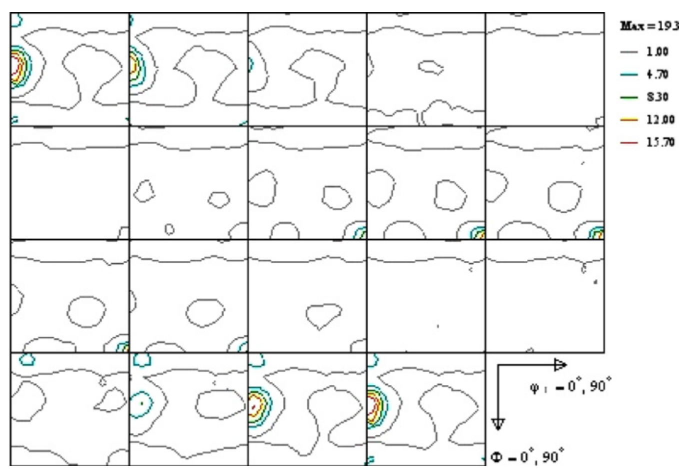

Fig. 4. Orientation distribution function (ODF) measured using X-ray diffraction.

both the chemical composition of second phase particles of the alloy and the fatigue fracture surface.

3. Results and discussion

3.1. Microstructure and texture

Fig. 2 shows the microstructure of the AA2524 alloys. It can be seen that the alloys were partially recrystallized, possessing a pan-caked grain structure which was elongated along the rolling direction. The SEM observation demonstrated that a large number of second phase particles parallel to the rolling direction can be found in the alloy as illustrated in Fig. 3(a) and (b). With the help of EDS in SEM, we analyzed the chemical composition of these particles, which showed that some particles containing Al, Cu, Fe, Mn elements were considered as Al_7Cu_2 (Fe, Mn) phase, and that the smaller particles containing Al, Cu, Mn was the dispense phase $Al_{20}Cu_2Mn_3$. These observations of the second phase particles were consistent with other investigations performed in Al–Cu–Mg alloys [2,16]. As shown in Fig. 4 and listed in Table 2, the measured texture of the sheet was found to be the recrystallized-type with Goss, Cube and P as the main texture component, which was consistent with the crystallized grain structures in samples. Most of the grains (about 67.93%) were randomly orientated.

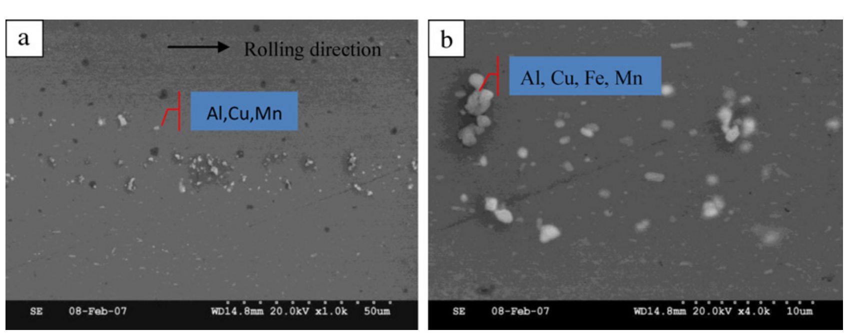

Fig. 3. SEM micrographs showing the distribution and composition of constituent particles in an AA 2524 alloy (a) particles elongated and aligned with the rolling direction and (b) the clustered Al_7Cu_2 (Fe, Mn) second phase particle.