International Journal of Fatigue 51 (2013) 8–14

Contents lists available at SciVerse ScienceDirect

International Journal of Fatigue

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

Technical note

Investigation of fatigue anisotropy in an extruded magnesium alloy

J.B. Jordon [a,*], H.R. Brown [b], Haitham El Kadiri [b], H.M. Kistler [b], R.L. Lett [b], J.C. Baird [b], A.A. Luo [c]

[a] Department of Mechanical Engineering, The University of Alabama, Tuscaloosa, AL 35487, United States
[b] Department of Mechanical Engineering, Mississippi State University, Mississippi State, MS 39762, United States
[c] General Motors Research and Development Center, Warren, MI 48090, United States

ARTICLE INFO

Article history:
Received 18 June 2012
Received in revised form 4 October 2012
Accepted 15 January 2013
Available online 23 January 2013

Keywords:
Fatigue
Mg AM30
Extruded
Transverse
Strain-life

ABSTRACT

This work presents an investigation on the fatigue behavior of magnesium AM30 alloy in the extruded and transverse directions. Experimental results from strain-controlled fatigue tests showed that the extruded direction exhibited a lower low-cycle fatigue life but a better high-cycle fatigue life compared to the transverse direction. Differences in the cyclic stress–strain response between the two directions were also observed. Lastly, scanning electron microscopy revealed that fatigue cracks predominantly initiated at cracked intermetallic particles.

1. Introduction

Wrought magnesium alloys show potential for use in automotive structural applications for the purpose of vehicle lightweighting and improved fuel economy. As such, increased efforts are underway to elucidate the fatigue behavior of various wrought magnesium alloys [1–6]. Unlike in cast alloys, extruded magnesium alloys exhibited anisotropic cyclic stress–strain behavior depending on loading direction relative to the crystallographic orientation. These experimentally observed differences in mechanical behavior are primarily due to the activation of twinning. Depending on the loading direction relative to the *c*-axis, twinning and detwinning can occur resulting in strong asymmetrical hysteresis loops. This anisotropy is illustrated in AZ31 (Mg–3Al–1Zn[1]) and AZ61 (Mg–6Al–1Zn) magnesium alloys [8,10], where the transverse orientation exhibited higher flow stresses under tensile loading compared to the extruded direction. Furthermore, the loading direction relative to the crystallographic orientation tends to influence the fracture mode, where the extruded direction typically behaves in a brittle manner compared to transverse direction [11]. However, the degree to which twinning-induced anisotropy is exhibited in the fatigue lifetimes has not been fully established. Recently, Jordon et al. [8] showed that while a strong anisotropy was present between tensile behavior of extruded and transverse orientations in AZ61 magnesium alloy, significant differences in fatigue lifetimes were not observed. They concluded that fatigue cracks initiating from intermetallic particles in both directions tended to negate the effect of crystallographic orientation on the final number of cycles to failure. This observation of fatigue cracks initiating from cracked intermetallic particles in magnesium alloys has also been observed in extruded AM30 (Mg–3Al–0.3Mn) magnesium alloys [7]. However, to the best of the authors' knowledge, an investigation on the effect of crystallographic orientation on fatigue in AM30 magnesium alloy has not been conducted. As such, the purpose of this paper is to quantify the strain-life fatigue behavior in the extruded and transverse orientations in the extruded AM30 magnesium alloy, including the cyclic stress response, and to identify sources of fatigue crack initiation.

2. Materials and experiments

The material of focus in this study is an extruded AM30 magnesium alloy in a crash rail form that was extruded at a rate of 2.7 m/min. The nominal composition of AM30 is given in Table 1. Specimens with a gage length of 20 mm, gage width of 4.5 mm and thickness of 2.5 mm and were machined from the rail parallel and perpendicular to the extruded direction. In order to remove any surface defects and surface residual stresses due to machining, each specimen was hand-ground in the longitudinal direction with respect to the loading axis starting with 300-grit and finishing with 800-grit silicon carbide sand paper prior to fatigue testing. Additional samples were machined, cold mounted in resin, and then polished to quantify the microstructural features of the as-received

---

* Corresponding author. Tel.: +1 205 348 2701.
E-mail address: bjordon@eng.ua.edu (J.B. Jordon).

[1] All composition in wt.% except otherwise stated.

0142-1123/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijfatigue.2013.01.006

Table 1
Nominal composition in weight percent of extruded AM30.

Al	Mn	Zn	Fe	Ni	Cu	Mg
3.4	0.33	0.16	0.0026	0.0006	0.0008	Balance

material. After polishing, the specimens were etched in a solution of 4.2 g picric acid, 10 ml acetic acid, 10 ml H_2O, and 70 ml ethanol. Electron backscatter diffraction (EBSD) technique was used to quantify microtexture, while the macrotexture was measured using neutron diffraction.

Monotonic tension tests were carried out for the extruded and transverse samples using an Instron electro-mechanical load frame at a strain rate of 0.001/s. Fatigue tests were conducted on an MTS servo-hydraulic load frame in strain control using a mechanical extensometer attached to the gage section of the specimens. In order to prevent the blades of the extensometer from initiating fatigue cracks, double-sided tape was placed in between the blades and the specimen gage section. The fatigue tests were performed at a range of strain amplitudes including 0.2%, 0.3%, 0.4%, and 0.5% under fully-reversed conditions ($R = -1$). All tests were conducted at 5 Hz in ambient laboratory temperature and relative humidity. During fatigue testing, the axial force was constantly monitored throughout the tests as to note any significant changes in the values of the extrema, which may indicate buckling in the gage section or slippage of the extensometer. For the fatigue tests, failure was defined as a 50% load drop in maximum tensile cyclic load. After failure, the fracture surfaces were cut from the specimens and mounted for scanning electron microscope analysis. The fracture surfaces of multiple specimens were investigated with the intent to determine the source of fatigue crack initiation. Energy dispersive spectroscopy (EDS) analysis was employed to determine the chemical composition of observed sources of crack initiation.

3. Results and discussion

Fig. 1a shows the inverse pole figure map and Fig. 1b shows the pole figures, both with extruded directions coming out of the page. The $\{0001\}$ and $\{10\bar{1}0\}$ pole figures from neutron diffraction measurements revealed a sharp double fiber. In fact, the first strong fiber corresponds to a major transverse direction (TD) || $[0001]$ component with an axial extruded direction (ED) || $\langle 10\bar{1}0\rangle$ component distribution perpendicular to TD. The second fiber is rather weak and corresponds to a normal direction (ND) || $[0001]$

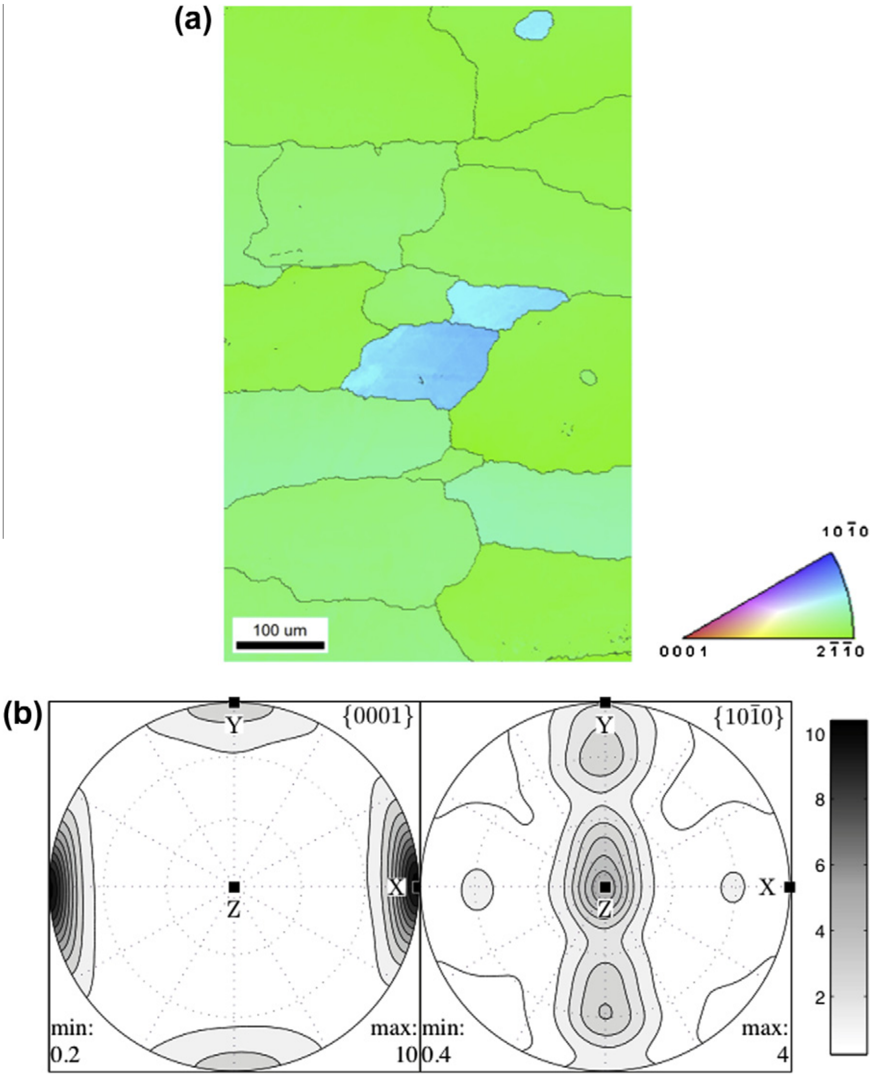

Fig. 1. (a) Inverse pole figure map for extruded AM30 Mg alloy and (b) the pole figures showing that the *c*-axis was perpendicular to the extrusion direction (extruded direction is out of the page).