Fatigue behaviour of ultrafine grained Al-7075 alloy produced by equal channel angular pressing (ECAP)

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Abstract

The aim of this paper was to examine the effect of equal channel angular pressing (ECAP) on microstructure and fatigue properties of Al-7075 alloy. The material was pressed up to two passes by route B\textsubscript{C} at room temperature. Followed by ECAP rotating bending fatigue test were performed and microstructural observations were undertaken using transmission electron microscopy (TEM) and scanning electron microscopy (SEM). Experimental results revealed significant improvement in fatigue behaviour of ECAPed alloy as compared with those of unECAPed alloys. Microstructure characterization by electron microscopy showed that the improvement of fatigue strength was due to the formation fine grains during ECAP. The effect of ECAP pass numbers on S-N curve and fracture surface is also discussed.

Keywords: Fatigue; ECAP; Microstructure; Fractography.

1. Introduction

Severe plastic deformation (SPD) is an efficient and reliable method for producing ultra-fine grain (UFG) materials, Furukawa et al. (1998). Equal channel angular pressing (ECAP) or extrusion (ECAE) is one of the SPD processes to produce bulk UFG materials, Segal (1995). Processing by ECAP is especially attractive because the procedure can easily be scaled-up to produce relatively large billets and the process present a potential for developing materials that may be used in a range of structural and functional applications, Horita et al. (2001). Severe plastic deformation by simple shear is induced by extruding the billet repetitively through a die with two channels of equal cross section intersect at an abrupt angle, $\phi$, and with a corner curvature angle, $\psi$, Xu and Langdon, (2003).
The 7xxx series Al–Zn–Mg and Al-Zn-Mg-Cu aluminium alloys have been extensively used as structural material due to their attractive widespread properties such as high strength to density ratio, ductility, toughness and resistance to fatigue, Jin-Feng et al. (2008), Shaeri et al. (2013). Since the fatigue failure is main factor responsible for the reduction in the service life of constructions, one of the crucial properties of these series for design is fatigue strength.

To date, investigations concerning the fatigue behaviour of Al alloys processed by ECAP were mostly performed on 2xxx, 5xxx and 6xxx series as well as Al-Li alloy, Chung et al. (2002), Patlan et al. (2001), Lapovok et al. (2006). However, in spite of the structural applications of Al-7075 alloy especially in aircraft construction, there has been no report to evaluate the fatigue behaviour of this important engineering alloy after ECAP.

In current research, the effect of ECAP on fatigue behaviour of Al-7075 alloy was investigated for the first time. There is an extensive knowledge on fatigue properties of classical engineering materials in textbooks and papers but this extensive knowledge cannot be directly transferred to UFG materials, Goto et al. (2001). Thus, the purpose of this work was to investigate the fatigue properties of UFG Al-7075 alloy produced by ECAP process.

2. Experimental

The Al-7075 alloy used in this research had the following composition in wt. % of 5.7 Zn, 2.65 Mg, 1.5 Cu, 0.21 Cr and balanced Al. Extruded aluminium rods were cut into round billets with diameter of 12.2 mm and length of 120 mm. Before ECAP process, the material was annealed at 415 °C for 2 h followed by furnace cooling. ECAP solid die used in this investigation had a channel angle of Φ=90° and an outer curvature angle of Ψ=20°. ECAP process was performed at room temperature with 1.5 mms⁻¹ pressing velocity for 2 passes, using B_C route (90° rotation around longitudinal axis after every pass). All fatigue tests were carried out under fully reversed load control at room temperature using a rotating bending fatigue machine operating at 30 Hz frequency.

Optical microscopy and transmission electron microscopy (TEM) using a JEOL JEM 3010 equipment operating at accelerating voltage of 300 kV was employed to measure the grain size of unECAPed and ECAPed alloys, respectively. Details of the sample preparation for TEM were reported previously and the observation procedures followed conventional practice, Shaeri et al. (2014). The fatigue fracture surfaces were also analyzed by scanning electron microscopy (SEM) using Vega Tescan set.

3. Results and discussion

3.1. Microstructure

Fig. 1 shows the optical photograph (etchant: Weck’s color Reagent) of the unECAPed alloy and TEM micrograph of 2 passes ECAPed alloy. As can be seen in Fig. 1a as well as EBSD results reported in our previous work, Shaeri et al. (2015), the microstructure of starting material consists of grains with grain size in the range of 10-80 μm, and subgrains with grain size less than 5 μm. TEM micrograph of 2 passes ECAPed alloy reveals that, the grains of initial material with mean grain size of about 40 μm refine to grains with mean grain size less than 700 nm after 2 passes of ECAP. It is obvious that the subgrains tend to be elongated parallel to the shear direction. Analysis of the SAED patterns in Fig. 1b reveals that the SAED patterns mainly consist of discrete spots showing considerable amount of the grain boundaries have low angles of misorientation.
Fig. 1. (a) Optical photograph (etchant: Weck’s color Reagent) of unECAPed alloy; (b) TEM micrograph of 2 passes ECAPed alloy.

3.2. Fatigue behaviour

Fig. 2 displays the S-N curve (Wöhler plot) of unECAPed, 1 pass and 2 passes ECAPed Al-7075 alloy. The S-N curve does not show horizontal segment, which is typical of many nonferrous metals and alloys. Therefore, the fatigue limit was determined on the base of $10^6$ cycles. As can be seen, the single pass of ECAP process has remarkable influence on the fatigue behavior of the unECAPed Al-7075 alloy. The fatigue life of 1 pass ECAPed alloy was substantially longer for all stress amplitudes than that of unECAPed alloy. The difference in fatigue life increases with an increase in stress amplitude. However, the degree of enhancement was largely reduced by further pressing (2 passes). Despite significant improvement in both the low and high cycle regimes after 1 pass of ECAP, 2 passes ECAPed alloy showed little enhancement just in the low cycle regime ($N<10^5$) compared to the unECAPed alloy. In the high cycle regime, fatigue strength of 2 passes ECAPed alloy tends to coincide with that of unECAPed alloy. The fatigue limit was approximately 70, 117 and 86 MPa for unECAPed, 1 pass and 2 passes ECAPed alloy, respectively. These magnitudes show an about 67% and 23% increase in the fatigue limit after 1 pass and 2 passes of ECAP, respectively. The similar results have been gained by Chung et al. (2002) and Akbaripanah et al. (2013). Chung and colleagues observed a significant enhancement in fatigue life of T6 treated commercial 6061 Al alloy after single pass of ECAP in both low and high cycle regime. For AM60 alloy, Akbaripanah and colleagues reported after two passes of ECAP, a large improvement in fatigue life occurs in all stress amplitudes. Similar to current research, in both investigations, the remarkable increase in fatigue life disappeared by further pressing.
3.3. Fractography

Fig. 3 shows the SEM micrographs of the fatigue fracture surfaces. Two components can be seen in the fracture surface of the unECAPed alloy (Fig. 3a): flat facets and large regions of fractures. Inside the large regions there are fatigue striations oriented parallel to each other in the adjacent regions. However, no dimple was observed in the fracture surface. This observation indicates that fatigue failure in the unECAPed alloy has characteristic features of the brittle fracture. Fracture surfaces of ECAPed alloys (Fig. 3b and 3c) showed a typical ductile fracture surface appearance. These observations imply that the brittle fracture mode is transformed into a ductile one after ECAP process. The voids on the fracture surfaces of ECAPed alloys are larger than the average grain size of the material before fatigue (700 nm). This finding reveals that the grain boundaries are considerably weak compared to the grain interior. So, it can be concluded that fatigue crack propagation mode changes from intergranular to transgranular after ECAP process.
4. Conclusions

All ECAPed alloys have demonstrated an enhanced fatigue limit. But this enhancement was remarkable in 1 pass ECAPed alloy.

The considerable improvement in the fatigue life of the Al-7075 alloy was gained just by 1 pass of ECAP process in both the low and high cycle regimes. In view point of economics, this result is excellent because the production rate increases by reduction in number of passes.

The brittle fracture mode of unECAPed alloy is transformed into a ductile one, and fatigue crack propagation mode changes from intergranular to transgranular after ECAP process.

References


