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Effect of Equal Channel Angular Pressing (ECAP) on Wear Behavior of Al-7075 Alloy

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Abstract

Equal-channel angular pressing (ECAP) is an effective fabrication process for obtaining ultrafine grained materials. In order to investigate the effect of grain refinement during ECAP on wear properties of Al 7075 alloy, the specimens were pressed up to four passes by route B_c at room temperature. Followed by ECAP, dry sliding wear tests have been conducted using a pin-on-disk machine under different loads of 10, 20 and 30N at a constant sliding speed of 0.23 ms⁻¹. Microstructural observations were undertaken using transmission electron microscopy (TEM) and the surface of worn specimens was investigated by scanning electron microscopy (SEM). The effect of load and ECAP process on the mass loss, have been explained with respect to microstructure and wear mechanism. Comparison of wear resistance of specimens shows that by using ECAP process, wear resistance of the specimens increases considerably due to the formation of very fine grains during ECAP.

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1. Introduction

Severe plastic deformation (SPD) is a trustworthy method for achievement of ultrafine-grained (UFG) materials, Zhilyaev et al. (2013). Equal channel angular pressing (ECAP) or extrusion (ECAE) is the most attractive, and potentially the most useful severe plastic deformation (SPD) technique, Kumar et al. (2012), Langdon (2007), Valiev and Langdon (2006). During ECAP process, the intense plastic strain can be achieved by simple shear by pressing the specimen through a die containing two channels, equal in cross section, intersecting at an angle of Φ with a corner curvature angle, Ψ , Xu and Langdon (2003), Xu and Langdon (2009). So, ultra-fine grained materials with grain sizes generally in the range of ~100 to 1000 nm can be produced by ECAP process, Valiev and Langdon (2006).

Aluminium alloys are extensively used in industrial, structural and transport applications due to their high strength, low density and excellent corrosion resistance. In recent years, heat treatable 7xxx series Al–Zn–Mg and Al–Zn–Mg–Cu alloys have received great interest as the main materials in aviation and aerospace applications as well as automotive and marine industries, Ortiz-Cuellar et al. (2011). The study of the tribological behavior of aluminum based materials is important because of its high strength/density ratio and high thermal conductivity. Aluminum by itself exhibits poor tribological properties, while many aluminum alloys could have reasonable wear resistance due to the distribution of hard second phase particles in a relative soft matrix, Venkataraman et al. (2000).

The objective of the current investigation is to study the tribological properties of Al-7075 alloys processed by equal channel angular pressing. For this purpose dry sliding wear tests have been conducted using a pin-on-disk machine under different normal loads. Surface of the specimens have been also analyzed by scanning electron microscope (SEM).

2. Experimental procedure

The experiments were conducted using Al-7075 alloy as the main ECAP material. The chemical composition of Al-7075 alloy is shown in table 1. Prior to ECAP, the as-received extruded rods were annealed for 1 h at 415°C and then cooled in the furnace. The Al-7075 rods were cut into cylindrical samples with diameter of 19.1 mm and height of 140 mm and then pressed through an ECAP die having a channel angle of $\Phi=90^\circ$ and an outer curvature angle of $\Psi=20^\circ$. The image of applied die was presented in our previous work, Shaeri et al. (2013). All billets were pressed up to 4 passes at room temperature with pressing speed of ~ 0.5 mm s⁻¹, using processing route B_C (90° clock wise rotation around the sample axis between each pass), Shaeri et al. (2013).

Table 1. The chemical composition of Al 7075 alloy.

Ti	Zn	Cr	Mg	Mn	Cu	Fe	Si	Al
0.02	5.70	0.21	2.65	0.04	1.50	0.09	0.07	Base

The microstructure of processed samples was analyzed by TEM using JEOL JEM 3010 equipment operating at accelerating voltage of 300 kV. Details of the sample preparation for TEM were reported previously and the observation procedures followed conventional practice, Shaeri et al. (2014).

Dry sliding wear test was carried out by pin-on-disk machine at a relative humidity of 50-65% at room temperature against the counter face of a hardened and polished disk made of AISI 52100 steel with HRC 61-64 hardness. The wear tests were conducted under nominal loads of 10, 20 and 30 N at a fixed sliding speed of 1.20 ms⁻¹. The samples weight was measured three times after every 300 m. Thus, the total distance of sliding was 900 m. Each test at a given load and sliding velocity was repeated three times.

After wear test, the topography and microstructure examination of the worn surfaces was carried out using a VEGA-TESCAN scanning electron microscope. Also, energy dispersive X-ray spectroscopy (EDX) was performed using the same SEM to analyze the worn surfaces.

3. Results and discussion

3.1. Microstructure

Figure 1 shows optical image of the starting material etched with Weck's color reagent (4 g Permanganate potassium, 1 g NaOH, 100 ml distilled water) and TEM micrograph of specimens subjected to four passes of ECAP process by route B_C. 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 the grain size in the range of 10–80 μm, and sub-grains with a grain size of less than 5 μm. TEM images of ECAP processed specimens reveal that, the grains of initial material with average grain size of about 40 μm refine to grains with average grain size less than 500 nm after 4 passes of ECAP. It is also apparent that the grains after four passes by route B_C are essentially equiaxed, and the microstructure is approximately homogeneous.

3.2. Wear properties

Figure 2 shows the effect of applied load and ECAP process on the wear mass loss during wear test at a sliding distance of 900 m. The figure shows that the mass loss was reduced considerably after 4 passes of ECAP process and increased with increasing of applied load of wear test. This reduction in the wear mass loss after ECAP process can be attributed to the grain refinement and the increase in the strength according to the Hall–Petch relationship.

3.3. Worn surface morphology

The SEM micrographs of the worn surfaces of unECAPed and 4 passes ECAPed alloy under applied loads of 10 and 30 N are shown in Fig. 3. The worn surfaces consist of a combination of adhesion regions, Plastic deformation bands along the direction of the sliding, and delamination. The material was detached from the pin during the delamination process and subsequently adhered to the steel disc. Then, with further sliding, the material adhered again to the pin surface.

The result of EDS analysis confirmed the presence Fe and O which proves the transfer of Fe from the rotating disk to the pin as well as the formation of an oxide layer (a mechanical mixed layer). Fig. 3 also shows that the worn surfaces of the specimens were mostly covered by oxide particles. The oxide particles formed on the overall worn surface of the pin contained a certain amount of iron, aluminium and oxygen as examined by EDS. The wear debris could entrap between the sliding surfaces and gets compacted due to the respective sliding and forms a tribolayer over the surface.

As shown in Fig. 3, the degree of adhesive wear increases as the applied load increases. By increasing the applied load, more material will be welded to the disk, as the contact area between the two sliding surfaces increases. Then, the welding increases the tendency toward delamination, which induces adhesive wear.

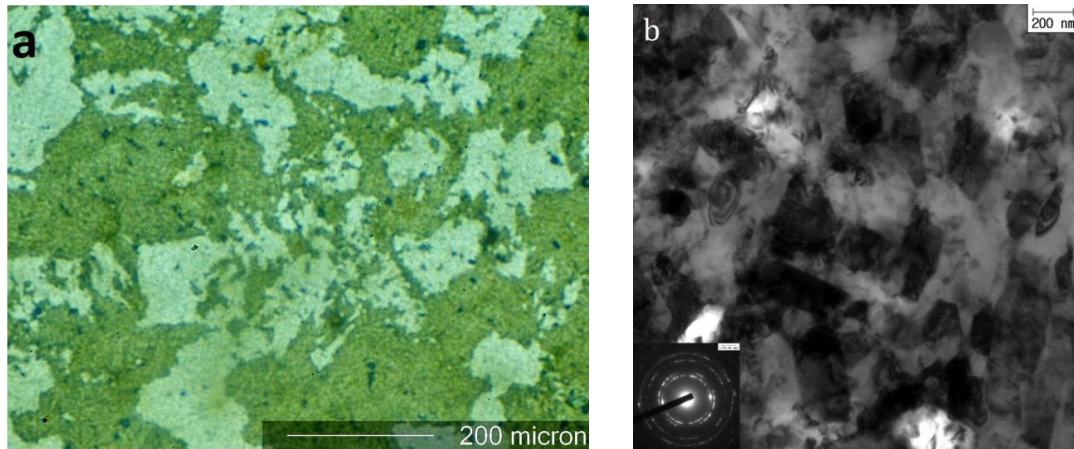


Fig. 1. (a) Optical image (etchant: Weck's color reagent) of starting material; and (b) TEM micrographs of the 4 passes ECAP processed Al-7075 alloy by route BC.

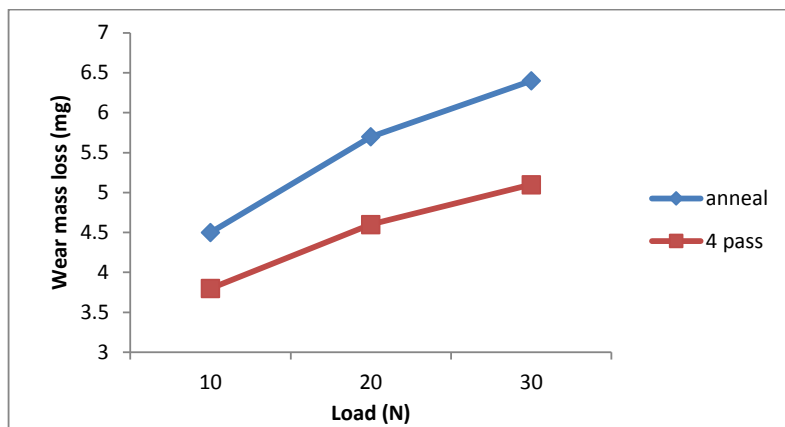


Fig. 2. Effect of pass number and applied load on the wear mass loss of Al-7075 under the sliding distance of 900 m.

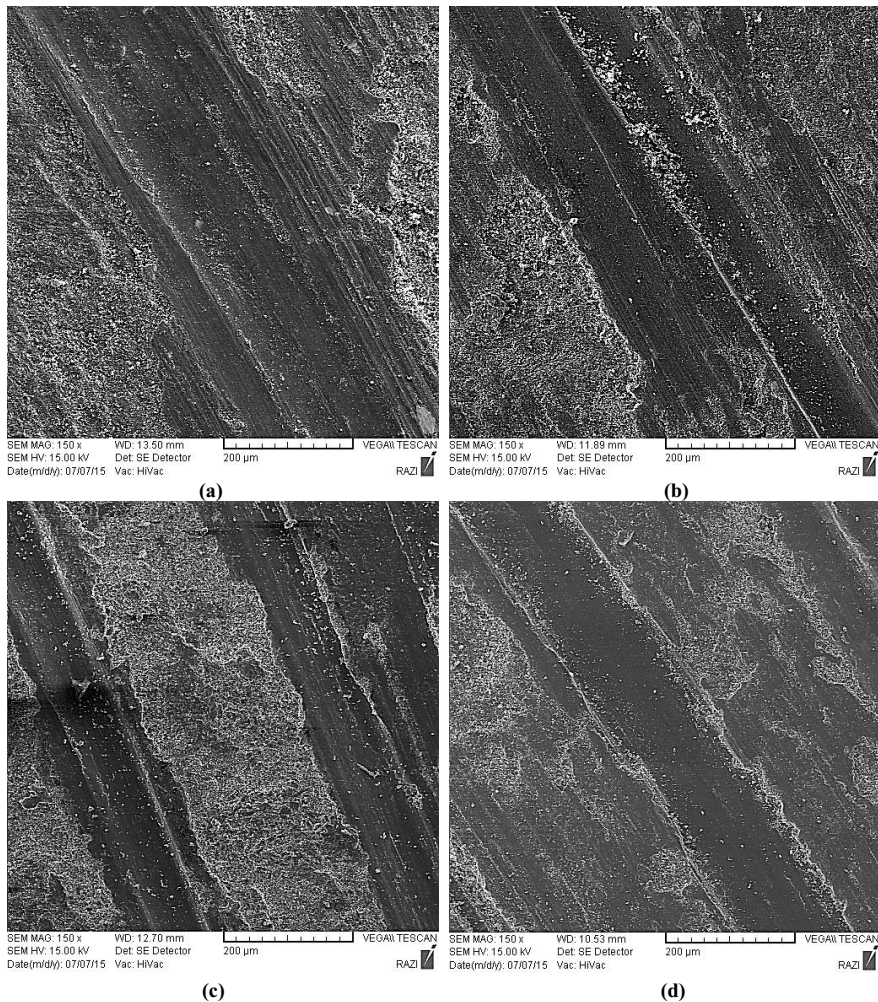


Fig. 3. SEM micrographs of the worn surfaces of the alloy (a) annealed (10 N); (b) 4 passes ECAPed (10 N); (c) annealed (30 N); and (d) 4 passes ECAPed (30 N).

4. Conclusions

In this paper, the wear properties of Al 7075 alloy processed by ECAP were investigated by means of pin-on-disc dry sliding test under various loads. The following conclusion can be drawn from this investigation:

- Wear test results show that the wear resistance of Al-7075 alloy was improved significantly by refining the grain size of the alloy during ECAP process.
- It is also apparent from sliding wear test that weight loss rate increases with increasing applied load of wear test.
- Worn surface investigation by SEM reveals that the wear mechanisms were observed to be adhesive wear as well as delamination.

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