Materials Science & Engineering A 644 (2015) 284–296

Contents lists available at ScienceDirect

Materials Science & Engineering A

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

Correlative evolution of microstructure, particle dissolution, hardness and strength of ultrafine grained AA6063 alloy during annealing

Seyed Masoud Ashrafizadeh, Ali Reza Eivani *

School of Metallurgy and Materials Engineering, Iran University of Science and Technology (IUST), Tehran, Iran

ARTICLE INFO

Article history:
Received 19 December 2014
Received in revised form
23 June 2015
Accepted 24 June 2015
Available online 28 June 2015

Keywords:
Sever plastic deformation
Annealing
Microstructure
Hardness
Strength
Particle size and distribution

ABSTRACT

In this research, evolution of hardness and strength in ultrafine grained AA6063 alloy during annealing is investigated and correlated to the evolution of microstructure and particle dissolution. After four passes ECAP, formation of ultrafine grained (UFG) structure with average grain size less than 1 μm is demonstrated. Evolution of hardness and strength in addition to the microstructural stability of the samples are investigated during annealing at 300–500 °C. At 300 °C, volume fraction recrystallized gradually increases by time and after 1 h, the sample is fully recrystallized. An in-line trend is observed for the evolution of hardness. In fact, hardness decreases gradually with annealing time as the volume fraction of recrystallization increases. However, at 350 and 420 °C, the samples are fully recrystallized after 30 s and consequently, a severe drop in hardness is observed. At 500 °C, the microstructure is quite unstable. By 10 and 30 s annealing, the samples exhibit fully recrystallized structures which turns to abnormal grain growth when the annealing time increases to 120 s. The average grain size is in general larger than the samples annealed at 350 and 420 °C. Therefore, a lower hardness is expected. However, an inverse trend is observed. In fact, hardness of the sample annealed at 500 °C is higher than those in the samples annealed at 350 and 420 °C. In addition, after the initial significant drop in hardness due to full recrystallization after 30 s at 500 °C, a gradual increase is observed. Higher hardness at 500 °C and its increase by annealing time are correlated to dissolution of second phase particles which contribute in more significant solid solution hardening.

1. Introduction

Sever plastic deformation (SPD) has been extensively used for production of bulk nanostructured materials. Among well-known SPD techniques, equal channel angular pressing (ECAP) is unique owed to its simplicity [1], mode of deformation [2], homogeneity of deformation [3], possibility of manufacturing with round [4] or rectangular [5] cross sections and possibility of being applied to different initial billet geometries like flat products [6] and in continuous mode [7]. By ECAP processing, grain refinement occurs together with significant strain hardening which results in remarkable enhancement of strength in engineering alloys [8]. The particle sizes and distribution may have mutual effects in ECAP. They may contribute in grain refinement as investigated by Nikulin et al. [9] or be subject of change in size and distribution depending on the nature of particles [10] and may contribute in strengthening of the ECAP products [9,11,12]. The most significant drawback of SPD techniques, is the considerable reduction in ductility which may limit the use of UFG products in some critical applications [13,14]. Of course, this does not mean that UFG materials with their unique mechanical properties are not desirable. However, they would be more applicable if stress relieved UFG materials are produced which can provide high elongation with remained high strength. Such stress relived and equiaxed grain structures are as well convenient for superplastic applications if they provide reasonable stability. Therefore, SPD processing followed by a controlled annealing treatment would be of interest to those applications looking for mutual improvement of strength and elongation or applications in superplastic deformation.

There are many research concerning the correlations between the physical, mechanical and corrosion properties of metals and the grain structure and the effect of annealing treatment on the development of microstructure [15–19]. It is generally desirable to apply an annealing treatment to promote grain refinement but inhibit grain growth, since a coarser grain structure is expected to indicate lower strength, hardness and elongation. However, in complex alloy systems, e.g., AA6063, in which lots of simultaneous metallurgical phenomena, e.g., precipitation, particle dissolution, grain growth, and etc., play role in determination of strength and ductility, some other characteristics of the alloy are subject to

* Corresponding author. Fax: +98 21 77 240 480.
E-mail address: aeivani@iust.ac.ir (A.R. Eivani).

http://dx.doi.org/10.1016/j.msea.2015.06.074
0921-5093/

Table 1
Chemical composition of the alloy used in this study.

Element	Al	Mg	Si	Zn	Fe	Cu	Cr	Mn
Wt%	Base	0.84	0.57	0.10	0.31	0.03	0.3	0.04

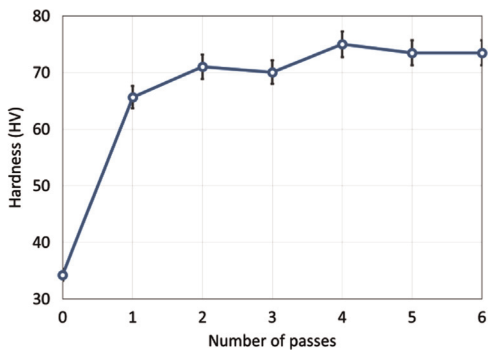

Fig. 1. Evolution of hardness by increasing number of ECAP passes.

change during annealing and may have consequent effect on the strength and ductility of the alloy. Recrystallization in cold or hot worked aluminum alloys and its effect on the evolution of hardness, strength and ductility has been extensively investigated [20–22]. In addition, there are lots of investigations on the precipitation hardening and it's contribution to strengthening of aluminum alloys [23,24]. However, to the knowledge of the authors, there is no study aiming at correlating the simultaneous

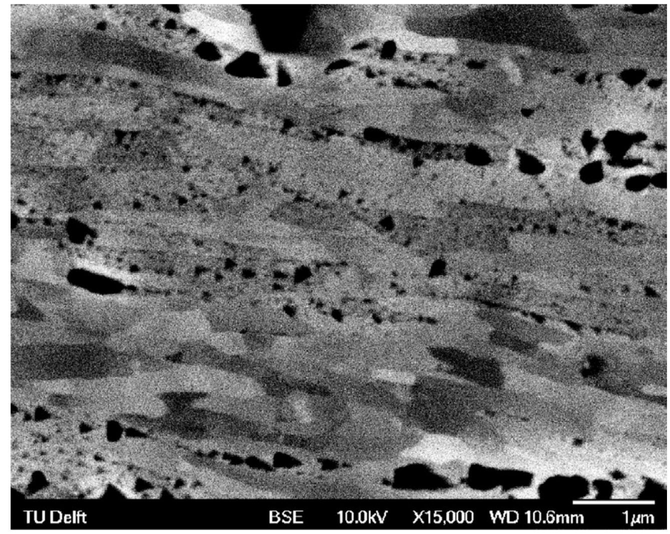

Fig. 3. Backscattered SEM image showing the nanostructure of AA6063 alloy after four passes ECAP. Micrograph is taken from the longitudinal cross section of the specimen.

effects of grain refinement, recrystallization and grain growth and dissolution or formation of precipitates on the evolution of mechanical properties of the alloy.

In this investigation, samples of ultrafine grained AA6063 aluminum alloy produced by ECAP are subjected to annealing aiming at obtaining the finest recrystallized and stress relieved microstructure with the highest strength. It is found that the evolution

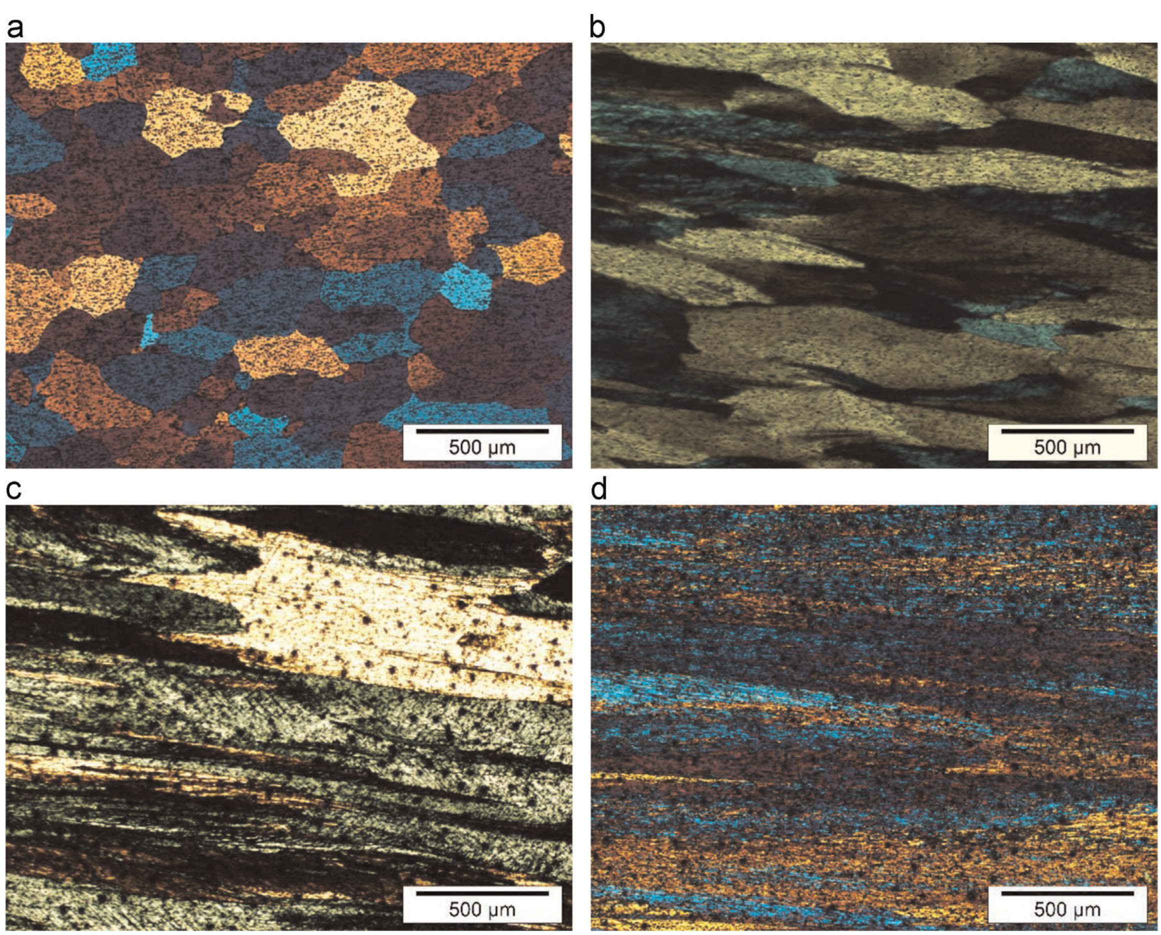

Fig. 2. Microstructure of the alloy (a) as-received and after (b) one, (c) two and (d) four passes ECAP.