Materials Science and Engineering A 528 (2010) 672–679

Contents lists available at ScienceDirect

Materials Science and Engineering A

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

Room-temperature compressive deformation behavior of Mg–Zn–Ca alloy processed by equal channel angular pressing

L.B. Tong [a,b], M.Y. Zheng [a,*], S.W. Xu [b], X.S. Hu [a], K. Wu [a], S. Kamado [b], G.J. Wang [c], X.Y. Lv [c]

[a] School of Materials Science and Engineering, Harbin Institute of Technology, Harbin 150001, Heilongjiang, PR China
[b] Department of Mechanical Engineering, Nagaoka University of Technology, Nagaoka 940-2188, Japan
[c] Northeast Light Alloy Company Limited, Harbin 150060, PR China

ARTICLE INFO

Article history:
Received 14 July 2010
Received in revised form
14 September 2010
Accepted 14 September 2010

Keywords:
Ultra-fine grain (UFG)
Coarse grain (CG)
Equal channel angular pressing (ECAP)
Mg–Zn–Ca alloy
Compressive deformation

ABSTRACT

The ultra-fine grained (UFG) Mg–5.25 wt.% Zn–0.6 wt.% Ca alloy was processed by equal channel angular pressing (ECAP), and the coarse grained (CG) alloy was prepared by subsequent annealing treatment. The microstructure, texture evolution and mechanical properties of the UFG and CG alloys during compressive deformation at ambient temperature were investigated. The results indicated that the dislocation slip was dominant in the UFG Mg alloy, and the compressive yield stress (CYS) of the UFG alloy was higher than that of the CG alloy due to grain refinement. In the CG Mg alloy, the activation of tension twinning also occurred in addition to basal slip, the work hardening rate was increased because of twin-induced additional hardening. Dynamic recrystallization (DRX) was observed in the CG alloy compressed to large strains at ambient temperature. Most of the $\{0\,0\,0\,2\}$ planes in both UFG and CG Mg alloys were rotated gradually to be perpendicular to the compressive direction (CD).

1. Introduction

Magnesium and its alloys are potential candidate materials for structural components in automobile and aerospace industry because of their low density and high specific strength and stiffness [1]. However, Mg alloys exhibit poor ductility at room temperature, due to their limited slip systems available [2]. Grain refinement is an effective way to improve the mechanical properties of Mg alloys. During the recent decades, equal channel angular pressing (ECAP) has emerged as a widely known procedure for the fabrication of ultra-fine grained (UFG) metals and alloys by introducing very large strains during deformation processing [3].

Both the grain size and crystal orientation have significant influence on the deformation behavior of Mg alloys. At room temperature, in addition to dislocation slip, twinning deformation is an important deformation mechanism of Mg alloys since twinning system can accommodate *c*-axis strain. Two types of twins have often been reported in Mg alloys: $\{1\,0\,\bar{1}\,2\}$ plane tension and $\{1\,0\,\bar{1}\,1\}$ plane contraction twins [4]. Tension twins are formed during the tension parallel to *c*-axis or compression perpendicular to *c*-axis, while the contraction twins are active when the tensile direction is perpendicular to *c*-axis or compressive is parallel to *c*-axis [5]. The grain refinement in Mg alloys restricts the activation of twinning deformation [6]. Barnett et al. [7] observed a transition from twinning to slip dominated flow with decreasing grain size when an as-extruded Mg–3Al–1Zn alloy is subjected to compressive deformation. The fiber texture with $(0\,0\,0\,2)$ basal plane and $\langle 1\,0\,\bar{1}\,0\rangle$ direction parallel to extrusion direction led to the activation of $\{1\,0\,\bar{1}\,2\}$ twinning when compressed along the extrusion direction, resulting in the lower compressive yield stress [8]. ECAP can refine the grain size and modify the texture of Mg alloys [9], which will have a significant influence on the deformation behavior. del Valle et al. [10] investigated the influence of texture and grain size on work hardening rate during the tensile deformation of ECAPed AM60 alloy. They reported that grain refinement caused a strong decrease in work hardening rate, and the texture had a great influence on work hardening behavior, for example, the ideal orientation of the basal planes (inclined about 45° to tensile axis) in the ECAPed AM60 alloy hindered the activation of prismatic slip, leading to an additional strain hardening. Zheng et al. [11] investigated the compressive deformation of ECAPed Mg–Zn–Y–Zr alloy at 423 K, a short region with high strain hardening rate was followed by a long steady state region with very low strain hardening rate. They considered that both grain refinement and texture with basal plane inclined 45° to ECAP direction suppressed the twin deformation in the UFG Mg–Zn–Y–Zr alloy, which resulted in a distinct work hardening behavior. However, the systematic investigations on the compression deformation behavior of UFG Mg alloys processed by ECAP are still insufficient, especially the evolution of microstructure and texture during the deformation process.

* Corresponding author. Tel.: +86 451 86402291; fax: +86 451 86413922.
E-mail address: zhenghe@hit.edu.cn (M.Y. Zheng).

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doi:10.1016/j.msea.2010.09.041

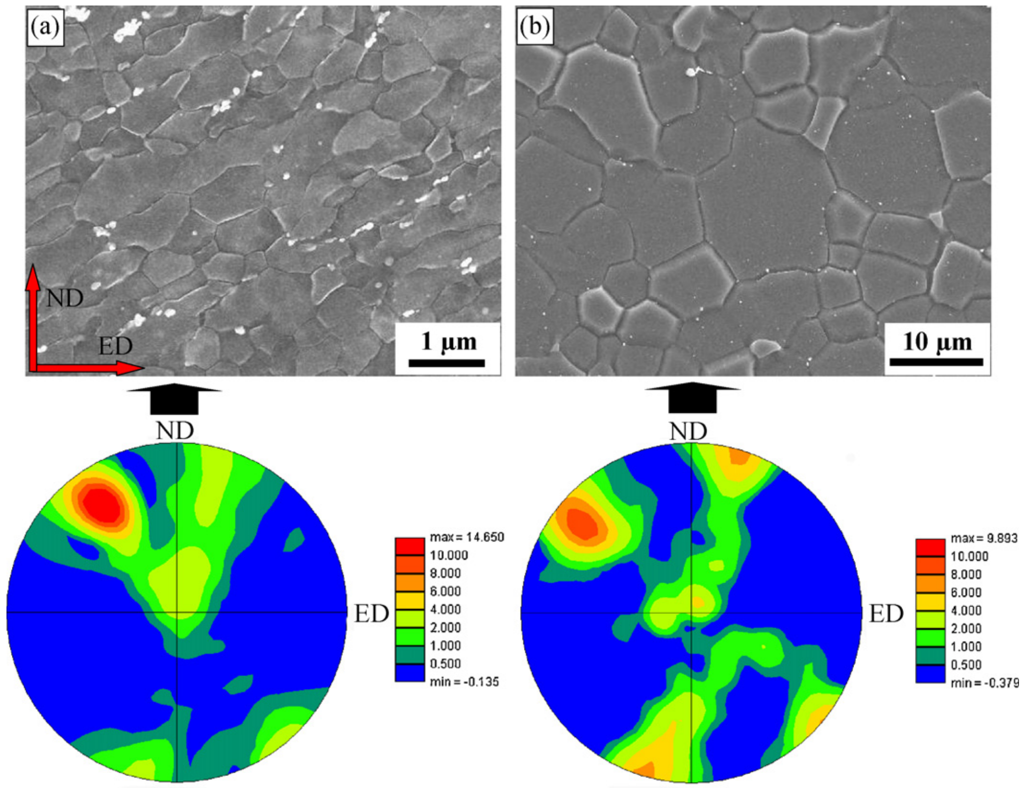

Fig. 1. SEM microstructure and basal plane pole figure of Mg–Zn–Ca alloy processed by (a) ECAP and (b) subsequent annealing.

Alloying Mg with Ca increases the strength and corrosion resistance [12], while the presence of Zn in the binary Mg–Ca alloys enhances the precipitation hardening response [13], consequently, Mg–Zn–Ca alloy with fine stable precipitates in the matrix has attracted great attention as heat-resistant Mg alloy with low cost in the recent years [14]. In addition, Ca is a major component in human bone and can accelerate the bone growth [15], thus Mg–Zn–Ca alloys have great potential for use in biodegradable and bioabsorbable implants [16]. In our previous work, the microstructural development and tensile properties of the UFG Mg–Zn–Ca alloy processed by ECAP have been studied [17,18]. The aim of this study is to investigate the deformation behavior of UFG and CG Mg–Zn–Ca alloys during the compression process at room temperature, with the main focus on the evolution of microstructure, texture and mechanical properties.

2. Experimental procedure

The Mg–5.25 wt.% Zn–0.6 wt.% Ca alloy was extruded at 300 °C with a reduction ratio of 12. The as-extruded alloy was cut into billets with a dimension of 10 mm × 10 mm × 70 mm. The outer and interior angles of ECAP die were $\psi = 37^\circ$ and $\Phi = 90^\circ$, respectively. The ECAP processing was conducted at 250 °C for 8 passes (corresponding to a total strain of $\varepsilon \approx 8.4$), using processing route Bc with constant displacement rate of 10 mm/s. Subsequently, the as-ECAPed alloy was annealed at 300 °C for 4 h to prepare the coarse grained (CG) alloy.

The specimens for microstructural observation and texture analysis were cut along *y*-plane, which was parallel to extrusion and normal direction (ED and ND). The rod-shaped compressive specimens with a diameter of 7 mm and a length of 10.5 mm were

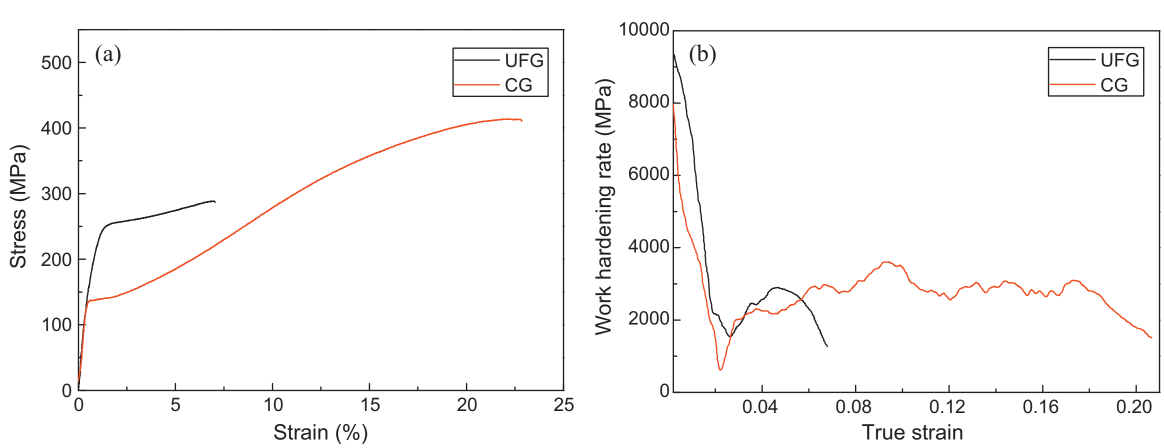

Fig. 2. Mechanical properties of UFG and CG Mg–Zn–Ca alloys: (a) compressive stress vs. strain curves, (b) work hardening rate vs. true strain curves.