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Full Length Article

The precipitation behavior of $MgZn_2$ and Mg_4Zn_7 phase in Mg-6Zn (wt.%) alloy during equal-channel angular pressing

Kai Yan [a,*], Jing Bai [b], Huan Liu [c], Zhao-Yang Jin [a]

[a] College of Mechanical Engineering, Yangzhou University, Yangzhou 225127, PR China
[b] College of Materials Science and Engineering, Southeast University, Nanjing 211189, PR China
[c] College of Mechanics and Materials, Hohai University, Nanjing 211100, PR China

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Abstract

As-extruded Mg-6Zn (wt.%) Alloy was subjected to severe plastic deformation (SPD) by the equal-channel angular pressing(ECAP) at 160 ºC. The results of tensile tests at room temperature showed that two passes ECAP resulted in a remarkable improvement of strength, yield strength from 200 to 265 MPa and ultimate tensile strength from 260 to 340 MPa. However, with the deformation increasing, the samples processed by ECAP for four or six passes had insignificant difference than that processed by two-pass ECAP. Massive precipitates were observed in all the Mg-6Zn alloys specimens processed by ECAP. Transmission electron microscope and X-ray diffraction results indicated that ECAP treatment induced the precipitation of laves $MgZn_2$ phase and transition Mg_4Zn_7 phase. The spherical $MgZn_2$ particles and irregular shape Mg_4Zn_7 particles coexist in the microstructure of Mg-6Zn alloy after six pass ECAP.

Keywords: Mg-Zn alloy; Equal-channel angular pressing (ECAP); $MgZn_2$; Mg_4Zn_7; Deformation induced precipitation

1. Introduction

It is well established that the severe plasticity deformation (SPD) is a highly effective strategy to refine grains of magnesium alloys to sub-micron even nanometer scale. These ultra fine-grained (UFG) Mg alloys show good superplasticity at high strain rate or at the lower temperature. Among these SPD technologies, equal-channel angular pressing (ECAP) is usually used to develop bulk UFG Mg alloys with record superplasticity ductility [1–3]. In addition to grain refinement, the severe plasticity deformation during ECAP also can induce intermediate phase precipitation from supersaturated solid solution for some specific Mg alloys, leading to some irregular variation in mechanical properties [4,5]. In this work, the granular Laves $MgZn_2$ precipitation was observed in ECAPed Mg-6Zn(wt%) alloys, and this article further concentrates on the process of phase transformation as well as the structure of Laves $MgZn_2$ precipitates induced by multi-pass ECAP in Mg-6Zn alloy.

* Corresponding author. College of Mechanical Engineering, Yangzhou University, Yangzhou 225127, PR China.
E-mail address: yank319@126.com (K. Yan).

2. Experimental material and procedures

The Mg-6Zn (wt%) alloy was prepared in a mild steel crucible under the protection of a mixed gas atmosphere of SF6 and CO2 by using the commercial pure stock of Mg, Zn, and Al. The melt was held at 680 °C for 30 min and then poured into a cylindrical iron mold with 60 mm in diameter. The as-casted billet was extruded into round bar with 15 mm diameter at 200 °C and then was machined into specimens dimensions of $\Phi 15\times 80$ mm^3.

ECAP were performed in an ECAP equipment with a 90 degrees internal angle between two channels and via route B_C. ECAP temperature was in the range of 160 ± 5 °C and pressing speed was about 1.5 mm/s. ECAP equipment was heated up to working temperature and then the specimen was put into ECAP mold to heating for 5 minutes. The lubricant was the mixture of graphite powder and Vaseline with a mixing ratio of 1:1.

Tensile properties were determined from tensile specimens of 5 mm gauge diameter and 25 mm gauge length and a loading rate of 1 mm min^{-1}. Microstructure observations were carried out on a Hitachi S-4800II field-emission scanning electron microscope(SEM) at 15Kv. The microstructure was characterized on an FEI Tecnai G2 field-emission transmission electron

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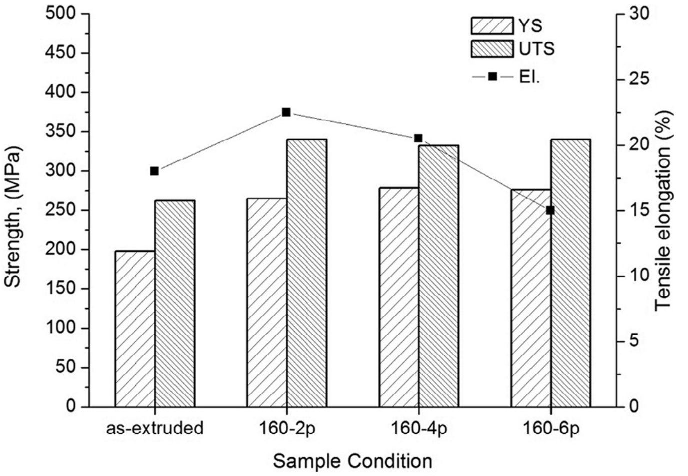

Fig. 1. Tensile properties of all the investigated samples.

microscope(TEM) at 200Kv. X-ray diffraction (XRD) date was obtained on a Bruker-AXS D8 advance polycrystal X-ray diffractometer.

3. Results and discussion

Fig. 1 shows the mechanical properties of all the samples. After two passes ECAP, the yield strength(YS) and ultimate tensile strength(UTS) is raised from 200 and 260 MPa to 265 and 340 MPa, respectively, and tensile elongation increased from 18 to 22.5%. With the further increase of ECAP passes, its strengths have no obvious changes. However, after four and six passes, the elongation reduced from 22.5% to 20.5% and 15%.

Fig. 2(a)-(d) shows the SEM images of the experimental Mg-6Zn alloy specimens before and after ECAP for two, four and six passes at 160 ºC, respectively. In the as-extruded (before ECAP) alloy, the microstructures with crack eutectic phase and fine intermediate phase particle is observed (shown in Fig. 2(a)). With the increasing of ECAP pass, the bulk eutectic phase gradually transforms into particle cluster by deformation process. After two passes ECAP, the huge number of fine precipitates has emerged and mainly localized around bulk eutectic phase (shown in Fig. 2b). After four passes ECAP, the precipitates increase further and there are many precipitation particles distributed far from eutectic phase (shown in Fig. 2c). Compared with that processed by two passes, the precipitates also obviously grow up and some larger particles are approximately 500 nm (shown in Fig. 2d). By comparing the SEM images, thereafter, it is found that there is no obvious change in the microstructure with the increasing of ECAP pass.

Transmission electron microscopy (TEM) images and selected area electron diffraction (SAED) pattern of the precipitates in a sample processed by six passes at 160 °C are shown in Fig. 3. It is seen that a stripe-like structure consists of small particles (as shown in Fig. 3a) which may be a part of crushed eutectic phase and these small particles were in the diameter range from decades nanometer to one micrometer. A TEM image and a SAED pattern recorded from an irregular shape particle in the stripe-like structure are provided in Fig. 3b and Fig. 3c. The SAED pattern can be indexed according to a monoclinic structure, with lattice parameters a = 2.596 nm, b = 0.524 nm, c = 1.428 nm and β = 102.5 degree, which is

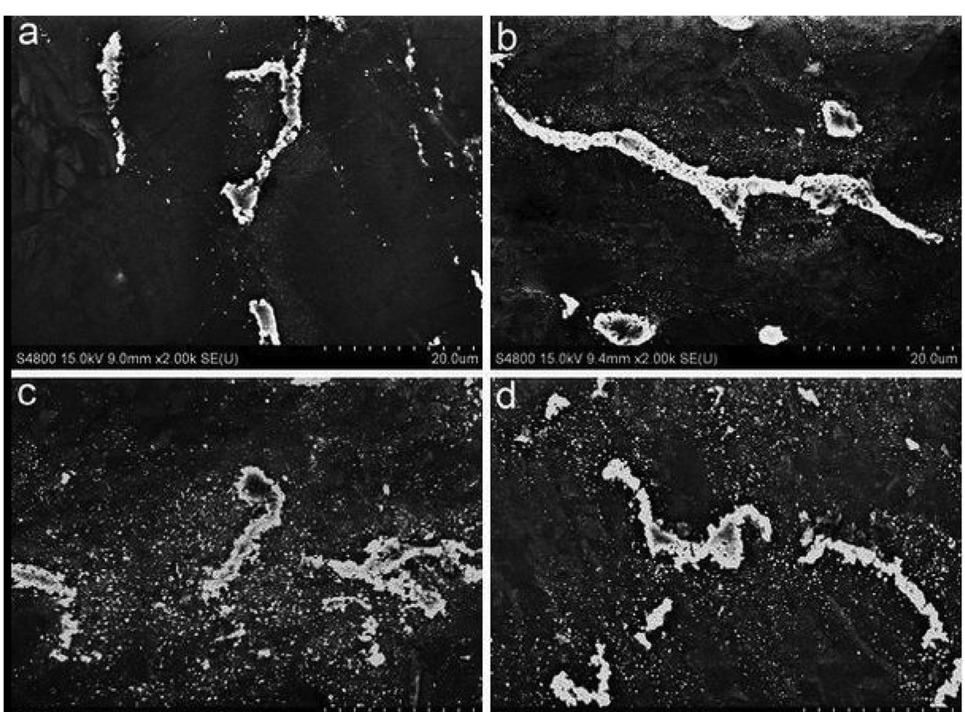

Fig. 2. SEM micrographs of the Mg-6Zn alloy processed by ECAP at 160 °C: (a) and (b) as-extrude, (c) and (d) ECAP for two passes, (e) and (f) ECAP for four passes, (g) and (h) ECAP for six passes.

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