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Dynamic microstructural changes during hot extrusion and mechanical properties of a Mg–5.0 Zn–0.9 Y–0.16 Zr (wt.%) alloy

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A B S T R A C T

In this study, firstly, dynamic microstructural changes of an as-cast Mg–5.0 Zn–0.9 Y–0.16 Zr (wt.%) alloy (designated ZWK510) during hot extrusion at 350 °C and a ram speed of 3.33 mm s^{-1} was systematically investigated by electron backscattering diffraction (EBSD) analysis. The dynamic recrystallization (DRX) mechanism during hot extrusion was discussed. Then, the effect of microstructure and texture on the mechanical properties of the as-extruded alloy specimens at room temperature was discussed. The as-cast ZWK510 alloy consists of *a*-Mg and quasicrystalline I-phase. During hot extrusion at 350 °C, the main DRX mechanism is the continuous DRX near the original grain boundaries. The I-phase can accelerate the DRX behavior near these areas by obstructing the slip of dislocations. The deformation twins and massive blocky substructures formed in original grains can coordinate the DRX process near the original grain boundaries, however the DRX seldom occurs inside of these area. After further deformation, these deformation twins and massive blocky substructures are elongated along the material flow and become so-called unDRXed area, then a bimodal "necklace structure" composed of fine DRXed grains of about 2.1 μm and unrecrystallized coarse area is formed. The extruded ZWK510 alloy shows a DRX ratio of about 58% and a typical basal fiber texture of $(0\ 0\ 0\ 1)\langle 1\ 0\ \bar{1}\ 0\rangle_{matrix}$// extrusion direction (ED). In the DRXed area around the crushed eutectic I-phase a large number of fine I-phase precipitates are observed pinning at the newly formed DRXed grain boundaries. The 0.2% proof strength and the ultimate tensile strength of the extruded ZWK510 alloy specimen are 317 and 363 MPa, respectively, with an elongation to failure of 12%, which have been attributed to strong basal fiber texture, refined grain size as well as the existence of fine precipitates formed during the hot extrusion.

1. Introduction

The development of high strength wrought magnesium (Mg) alloys is strongly desired to reduce the weight of transportation vehicles due to the increasing demand to reduce carbon dioxide emissions in the transportation sector. On the other hand, few applications of wrought magnesium alloys have been explored because of a number of drawbacks, such as lack of formability at room temperature and the 0.2% proof strength of Mg alloys is relatively low compared to that of aluminum (Al) alloys [1]. In order to compete with Al alloy, the 0.2% proof strength of wrought Mg alloy needs to be improved to over 300 MPa with a tensile elongation of over 10%.

The strength of Mg alloy is proved to be determined by the combined contributions of grain size refinement strengthening [2], solid solution strengthening plus dispersion and precipitation strengthening [3–7] and control of texture [8]. The Hall–Petch coefficient for Mg is ~0.7 MPa $m^{-1/2}$ [9], which is significantly higher than that of Al alloy [10]. Thus, grain refinement based on the understanding of dynamic recrystallization (DRX) mechanisms during thermomechanical processes makes a significant contribution to improving the strength of wrought Mg alloys. Recently, high strength wrought Mg alloys having 0.2% proof strength and ultimate tensile strengths of >300 MPa have been developed in Mg–Ca–Zn [11], Mg–Zn–Mn–Al [12], Mg–Gd–Y–Zn–Zr [13], Mg–Zn–Ag–Ca–Zr [14] and Mg–Zn–Ca–Zr [15] alloy systems using grain size refinement by hot extrusion. In these alloy systems stable secondary-phase particles are contained, so grain boundaries could be pinned with these dispersed or precipitated secondary-phase particles to inhibit grain growth, i.e., the mechanical properties of wrought Mg alloys with stable secondary-phase particles can be improved by microstructural control during thermomechanical processes.

Wrought Mg–Zn–Y–Zr alloys, which consist of a thermally stable icosahedral quasicrystalline phase (Mg_3Zn_6Y, I phase) formed in situ as a second phase in the *a*-Mg matrix during solidifica-

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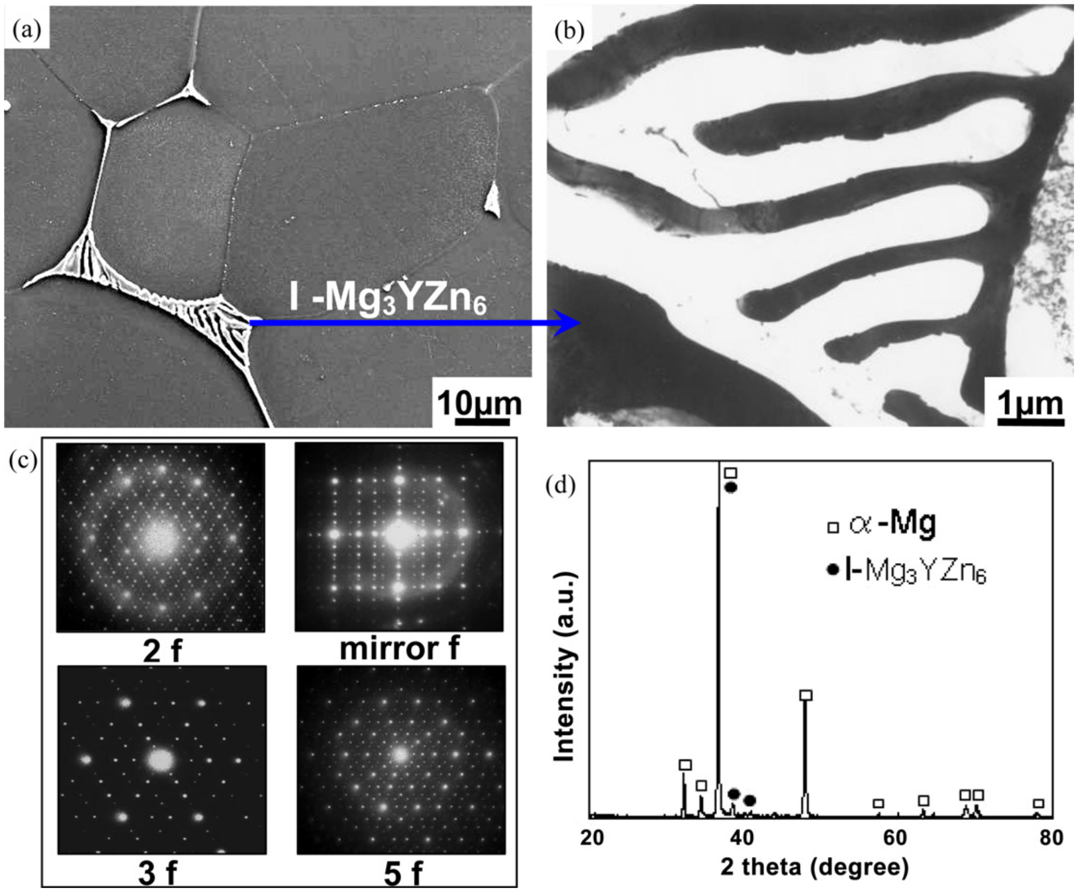

Fig. 1. Typical microstructures and XRD pattern of the as-cast ZWK510 alloy specimen. (a) SEM image, (b) TEM micrograph of eutectic I-phase (bright field image), (c) SADP from I-phase exhibiting 2-fold, mirror fold, 3-fold and 5 fold symmetry and (d) XRD pattern.

tion, have attracted much attention. Quasicrystals are isotropic and possess a specially ordered lattice structure called the quasiperiodic lattice structure [16]. Quasicrystal I-phase has high hardness, thermal stability, high corrosion resistance, low coefficient of friction, low interfacial energy, etc. [17]. Therefore, during hot deformation of Mg–Zn–Y–Zr alloy that contains I-phase, hard I-phase particles are stable against coarsening and can effectively obstruct the slip of dislocations [16–18]. Up to now, fine-grained Mg–Zn–Y–Zr alloys reinforced by quasicrystalline I-particles have been successfully developed by thermomechanical processes such as hot extrusion [16,18,19], hot compression [21] and equal channel angular pressing (ECAP) [22–24], etc. In these studies, mechanical properties at room temperature [18–20,22], superplastic behaviors at high temperatures [16,22–24], precipitation behavior during thermo-mechanical treatment [18], effects of yttrium on the microstructure and mechanical properties of Mg–Zn–Y–Zr alloys [19], etc., have been investigated. However, up to now there have been limited studies addressing the dynamic microstructural changes during thermomechanical processes, which make it difficult to further improve the mechanical properties of Mg–Zn–Y–Zr alloys through microstructural control.

In this study, firstly dynamic microstructural changes of an as-cast Mg–5.0 Zn–0.9 Y–0.16 Zr (wt.%) alloy during hot extrusion at 350 °C was systematically investigated by electron backscattering diffraction (EBSD) analysis. The DRX behavior during hot extrusion was discussed. Then, the effect of microstructure and texture on the mechanical properties of the as-extruded Mg–Zn–Y–Zr alloy specimens at room temperature was discussed.

2. Experimental procedures

The studied alloy was prepared by electric melting of high purity Mg, Zn and the Mg–Zr, Mg–Y master alloys under a cover gas mixture of CO_2 and SF_6 in a steel crucible and casting them into a steel mold. The composition of the alloy was Mg–5.00 Zn–0. 92 Y–0.16 Zr (wt%). Hereafter, the alloy is designated as ZWK510. The existence of icosahedral quasicrystalline I-phase in the *a*-Mg matrix of as-cast alloy specimen was confirmed by transmission electron microscopy (TEM, Philips CM 12) operated at 120 kV. TEM specimens were prepared by twin jet electro-polishing. Then, the as-cast ingot was directly extruded at 350 °C with an extrusion ratio of 9 and a ram speed of 3.33 mm s^{-1}.

In order to examine microstructure evolution during hot extrusion, extrusion was interrupted when the material had emerged ~6 mm from the die and the alloy then quenched in water. Samples for optical microscopy (OM) and scanning electron microscope (SEM) observation were etched in a solution of acetic picral after mechanical polishing. The average DRXed grain sizes and volume fraction of DRXed grain (designated as the DRX ratio) were measured using an Image-Pro Plus 5.0 software with more than 1000 grains and by more than five continuous OM images at a magnification of 200×. Dynamic microstructure and texture analyses by EBSD were conducted using a JEOL JSM-7000F scanning electron microscope (FESEM) operating at 25 kV equipped with TSL MSC-2200 software.

Specimens for tensile tests were machined from the as-cast and extruded alloy specimens. The specimens for tensile tests have a gauge length of 15 mm and cross sectional areas of 6 mm × 2 mm.