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Influence of deformation rate on microstructure, texture and mechanical properties of indirect-extruded Mg–Zn–Ca alloy

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ABSTRACT

As-cast Mg–5.3Zn–0.6Ca (weight percent) alloy was indirectly extruded at 300 °C with different deformation rates (ram speeds of 0.1, 0.3, 0.5 mms^{-1}), and the microstructure, texture and mechanical properties of the as-extruded alloys were investigated in the current study. With the increase of deformation rates, the average size and volume fraction of dynamic recrystallized grains were remarkably increased. The basal fiber texture became weak in the as-extruded alloy with higher volume fraction of recrystallized grains, because most of the basal planes in these grains were tilted to extrusion direction about 30–40°. The higher deformation rate decreased the tensile yield stress due to the grain coarsening and basal texture weakening, while the elongation was improved, which was resulted from the enhanced work hardening rate.

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1. Introduction

Magnesium alloys are potential candidate materials for structural components in the transportation and aerospace industries, due to the low density and high specific strength and stiffness [1,2]. However, the poor ductility at ambient temperature of Mg alloys processed by gravity casting limits their industrial applications. Conventional hot extrusion processing is an effective way to improve the mechanical properties of cast Mg alloys [3–6], through the grain refinement during the dynamic recrystallization (DRX) process.

The Mg–RE (rare earth) alloys (such as Mg–Gd–Zr, Mg–Gd–Y–Zn–Zr and Mg–Y–Zn systems [7–10]), prepared by the thermomechanical processing, exhibit the extraordinary high-strength and moderate elongation [11], but they require large quantity of the expensive RE elements, which increases the cost of Mg alloys [12]. Recently, the low-cost wrought Mg–Zn–Ca series alloys have attracted great attention, due to their excellent mechanical properties [13–16]. Zhang et al. [17] reported the extruded Mg–1.0Zn–0.5Ca (wt.%) alloy exhibited the excellent ductility at ambient temperature, with elongation of 44% and ultimate tensile strength of 215 MPa. The extruded Mg–5.99Zn–1.76Ca–0.35Mn (wt.%) alloy, with its tensile 0.2% proof stress of 289 MPa and elongation to failure of 16%, was reported by Xu et al. [18], the superior mechanical properties were attributed to the combined effect of fine dynamic recrystallized (DRXed) grains, a large number of dense precipitates and pronounced basal texture.

The improvement of mechanical properties of extruded Mg–Zn–Ca alloy is mainly influenced by the microstructure and texture evolution, which is related to the DRX behavior during hot extrusion. Therefore, how to achieve both the grain refinement and texture strengthening effects in Mg–Zn–Ca alloy is the key point to improve the mechanical properties. Up to now, many researchers have studied the extrusion parameters on the microstructure and mechanical properties of commercial Mg–Al–Zn (AZ) series alloys [19–21], but the systematic investigation on the extrusion technology of Mg–Zn–Ca alloy is rarely reported, especially the extrusion rate on the mechanical properties is remained unclear. Furthermore, the low surface quality of extruded Mg–Zn–Ca alloy is another problem which needs to be resolved, because the high Zn content increases the hot cracking tendency during the extrusion, and thus how to improve the quality of extruded Mg–Zn–Ca bar through optimizing the corresponding extrusion parameters is the basic precondition of achieving the preparation of Mg–Zn–Ca alloy with superior properties. The indirect extrusion technology is free of friction between the container and billet, and thus the extrusion pressure and surface cracking can be reduced. Moreover, the grain refinement effect can also be enhanced because of the decreasing frictional heat during the extrusion, which is beneficial to the improvement of mechanical properties. The aim of this work is to investigate the effect of deformation rate on the microstructure, texture and mechanical properties of indirect-extruded Mg–Zn–Ca alloys, and clarify the corresponding influence mechanisms.

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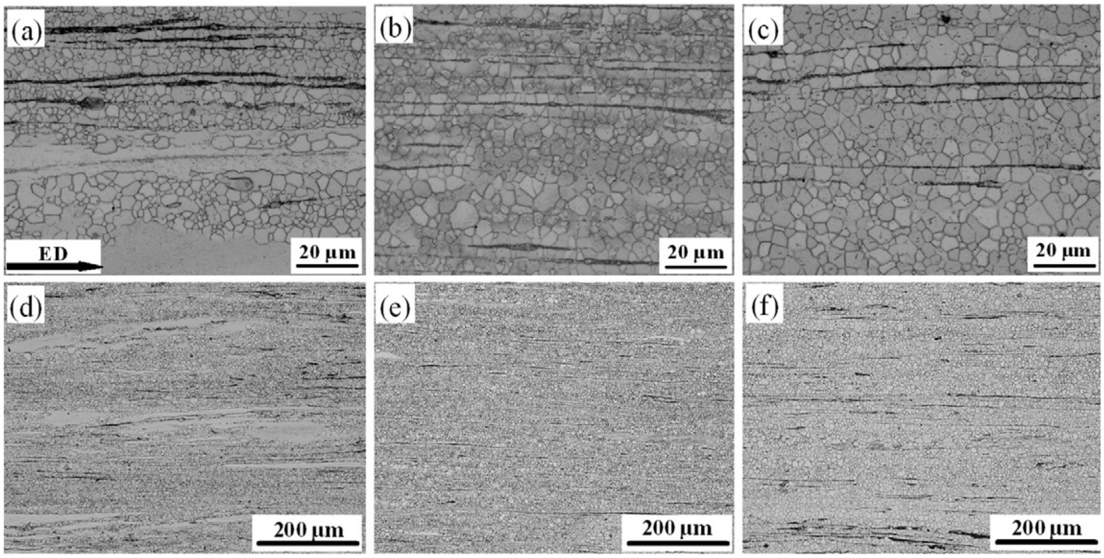

Fig. 1. Optical microstructures of the as-extruded alloys with different ram speeds: (a) and (d) 0.1 mms^{-1}, (b) and (e) 0.3 mms^{-1}, and (c) and (f) 0.5 mms^{-1}.

2. Experimental procedures

The Mg–5.3Zn–0.6Ca (wt.%) alloy was initially prepared by conventional gravity casting, using an electric resistance furnace under a SF_6 and CO_2 protective atmosphere. The melts were held at 700 °C for 10 min and then cast into a steel mold, and the diameter of cast ingot was 50 mm. The as-cast ingots were extruded at 300 °C with different ram speeds (0.1, 0.3 and 0.5 mms^{-1}), and the extrusion ratio was 20:1. The soaking time before extrusion was 10 min, and the extruded bars were cooled down in the air after extrusion.

The specimens for microstructural observation were cut along the longitudinal planes of extruded bars. The microstructure was observed using an Olympus DP11 optical microscopy (OM) and a Philips-CM12 transmission electron microscope (TEM) operating at 120 kV, the average grain size was measured using the software of Image-Pro Plus 5.0 with the grain number of more than 1000. The distribution of misorientation angle and texture analysis were examined by a JEOL FESEM JSM-7000F scanning electron microscopy (SEM) equipped with TSL MSC-2200 electron backscattered diffraction (EBSD) system, and the data was analyzed using OIM4.6 software. The tensile specimens, with the gauge length of 20 mm and diameter of 4 mm, were machined from the extruded Mg–Zn–Ca bars along the extrusion direction (ED). The tensile tests were conducted on Instron 5569 tensile machine at room temperature, with the strain rate of 1×10^{-3} s^{-1}.

3. Results and discussion

3.1. Microstructure

The average grain size of as-cast Mg–Zn–Ca alloy was calculated as ~150 μm, most of secondary phases ($Ca_2Mg_6Zn_3$) were distributed along the grain boundaries, and more detailed microstructure were reported in our previous study [22]. Fig. 1 shows the optical microstructures of the as-extruded Mg–Zn–Ca alloys with different deformation rates (ram speeds). With the increase of deformation rate, an obvious grain coarsening effect was observed (as shown in Fig. 1a, b, c), and the average DRXed grain size was calculated as 2.5, 3.5 and 4.0 μm in the as-extruded alloys with ram speed of 0.1, 0.3 and 0.5 mms^{-1}, respectively. Furthermore, the as-extruded alloy with lower deformation rate showed a typically bimodal grain structure distribution composed of DRXed fine grains with aspect ratio below 2.0, and unDRXed coarse grains with aspect ratio above 3.0 (Fig. 1d), which were elongated along the ED, representing the partially recrystallized structure, the volume fraction of DRXed grain was measured as 85.1%. With the increase of ram speeds, the equiaxed grain structure became more homogenous, the volume fraction of DRXed grain was increased to 97.3% (Fig. 1e) and 99.3% (Fig. 1f), respectively. The distribution of secondary phase was very similar in the as-extruded alloy with different ram speeds, the stringers of secondary phase with dark

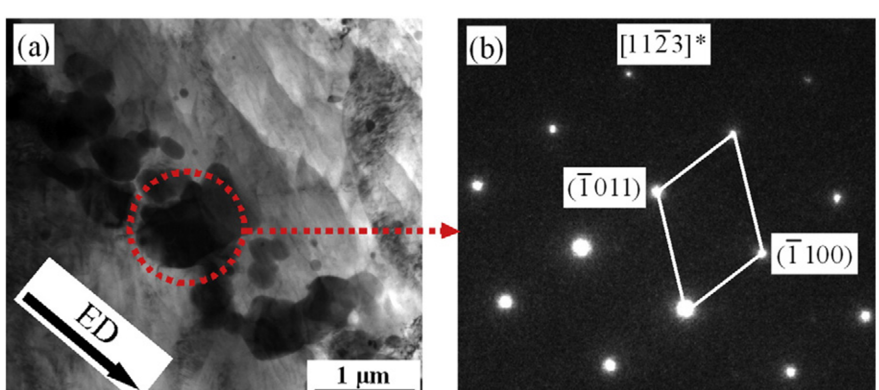

Fig. 2. TEM graphs of the as-extruded Mg–Zn–Ca alloy with ram speed of 0.1 mms^{-1}: (a) bright-field image and (b) SAED analysis.

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