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Full length article

Microstructure and mechanical behavior of the Mg–Mn–Ce magnesium alloy sheets

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Abstract

The microstructural evolution and mechanical behavior of Mg–Mn–Ce magnesium alloy were investigated in the present study. Mg alloy was prepared with metal model casting method and subsequently hot extruded at 703 K with the reduction ratio of 101:1. The grains were dynamically recrystallized after the extrusion process. Moreover, the (0002) pole figure of Mg–Mn–Ce alloy developed a splitting of pronounced basal texture. The mechanical properties were different due to different angles between *c*-axis and loading direction (0°, 45° and 90°) in the tensile tests. This significantly induces an asymmetry in the yield behavior. The Mg–Mn–Ce alloy exhibits a classical dimple structure as a result of slip accumulation and ductile tear.

Keywords: Mg alloy; Microstructure; Mechanical properties; Texture; Extrusion

1. Introduction

The applications of magnesium alloys are being increasingly evaluated for aerospace and automotive components due to their high specific strength, low density and excellent machinability [1–4]. Compared with casting counterparts, wrought magnesium alloys have better mechanical properties [5]. However, most wrought magnesium alloys usually bring about a strong texture during the primary processing such as the extrusion and the rolling [6], which is related to their limited number of active deformation systems in hexagonal close-packed (hcp) crystal structure [7,8]. This leads to a high directional anisotropy of mechanical properties. Basal $<a>$ slip, prismatic $<a>$ slip and pyramidal $<a+c>$ slip provide only four independent slip systems [9]. In general, basal $<a>$ slip systems can easily activate in Mg alloys at room temperature, while the prismatic $<a>$ and the pyramidal $<a+c>$ slip systems can operate only if a higher driving force is applied or deformed at elevated temperature because of their high critical resolved shear stress (CRSS) [10,11]. This can further limit the applications of magnesium alloys.

Mg–Mn–Ce system constitutes a promising alloy base for expanded components [12–14]. The addition of cerium is known to improve the strength and elevated temperature properties of magnesium alloys. It also results in the grain refining efficiency [15]. The well-dispersed second phase particles restrict grain growth and postpone cavitation to higher strain levels to obtain the enhancement in the hot

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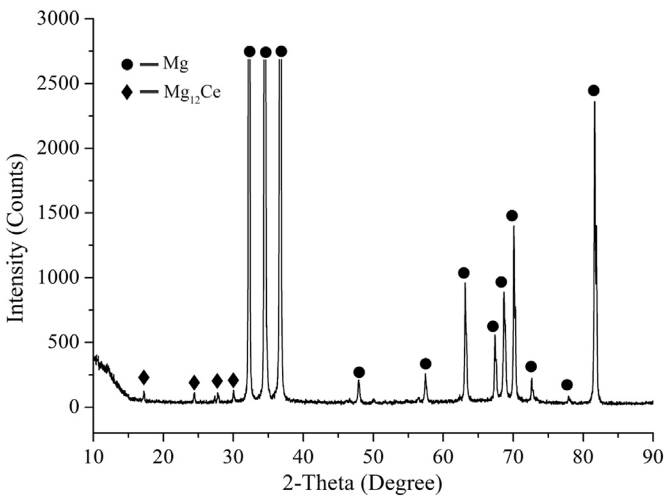

Fig. 1. X-ray diffraction pattern of the Mg−1.5Mn−0.5Ce alloy.

formability [16,17]. On the other hand, Manganese is used in magnesium alloys to lower the iron content and improve the corrosion resistance. It is also known that magnesium alloys containing manganese exhibit good ductility, making it possible to form sheet and tubes [12]. The peritectic reaction results in the formation of Mg solid solution (α-Mg) and α-Mn in Mg−Mn alloys [18]. It can be assumed that Mg alloys containing both Ce and Mn show a good base for the development of casting and wrought alloys. In present work, desired Mg−Mn−Ce alloy was prepared with metal model casting method and subsequently extruded. The microstructure and mechanical behavior were investigated.

2. Experimental procedure

Pure Mg (99.9 wt.%), Mg − 4.27 wt.% Mn and Mg − 20 wt.% Ce master alloys were used to prepare the desired Mg−1.5Mn−0.5Ce alloy. Melt was prepared in an electrical resistance furnace protected by mixture gas of 1 wt.% SF_6 − 50 wt.% CO_2 − 49 wt.% dry-air. The alloy was isothermally held at 993 K for 20 min and poured into a mild steel crucible and air cooled. The cast Mg−Mn−Ce billet was homogenized at 703 K for 2 h. The extrusion was conducted with an extrusion ratio of 101:1 at 20 mm/s extrusion rate. The extrusion temperature was 703 K. The extruded sheets were 56 mm in width (transverse direction, TD) and 1 mm in thickness (normal direction, ND).

Dog-bone tensile samples of 12 mm in gage length, 6 mm in width and 1 mm in thickness were machined from the sheets with various directions tilting 0°, 45° and 90° to the extrusion direction (ED), respectively. Tensile tests were conducted on a CMT6305-300KN universal testing machine at the initial strain rate of 10^{-3} s^{-1} at room temperature. The microstructures of the alloys were examined using optical microscopy (OM) and scanning electron microscope (SEM). The phase analysis and (0002) pole figures of Mg−1.5Mn−0.5Ce Mg alloy were carried out by X-ray diffractometer (XRD, Rigaku D/Max 2500) with Cu Kα radiation, a voltage of 40 kV and a current of 100 mA. The crystal orientation and misorientation angle distribution were examined by electron backscattered diffraction (EBSD). Following mechanical polishing, the specimens were prepared for EBSD by electro polishing at 20 V for about 150 s in the AC2 solution at −10 °C in order to remove surface strain. EBSD data was acquired using HKL Channel 5 System equipped FEI Nova 400 FEG-SEM. For orientation mapping the scan step size was set at 1 μm.

3. Results and discussion

To identify the presence of phases in the studied alloy, X-ray diffraction analysis was conducted. Fig. 1 shows the XRD pattern taken from the sheet. In addition to the Mg peaks, the reflection of $Mg_{12}Ce$ phase can also be indexed. Such an addition of cerium was helpful in the grain refining efficiency, and excess cerium reacted with magnesium to form the intermetallic.

Fig. 2 shows secondary, the backscatter SEM micrographs and EDS results of as-cast Mg−1.5Mn−0.5Ce alloy. It can be seen that $Mg_{12}Ce$ intermetallics locate in the grain boundary for the as-cast Mg alloy. The large number of second phases was well-distributed in a particle or rod-shaped in the Mg

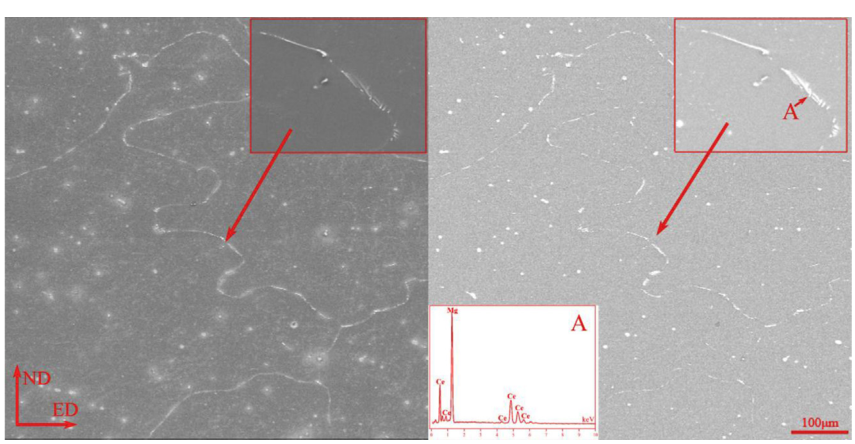

Fig. 2. The secondary, the backscatter SEM images and EDS results of as-cast Mg alloy.