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Effect of tensile direction on mechanical properties and microstructural evolutions of rolled Mg-Al-Zn-Sn magnesium alloy sheets at room and elevated temperatures

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ABSTRACT

In the present work, Mg-9Al-1Zn-0.4Sn (AZT910) magnesium alloy sheets with a fine-grained structure (~5 μm) and tilting basal texture were prepared by a 16-passes rolling process. Effect of tensile directions on properties and microstructural evolutions of the AZT910 alloy sheet at different temperatures, i.e. room temperature, 200 and 300 °C, respectively, were investigated by using three kinds of tensile specimens (rolling direction (RD), transverse direction (TD) and 45° towards RD). Experimental results showed that tensile properties exhibited a strong dependence on tensile directions at room temperature and 200 °C, while a negligible dependence at 300 °C. The anisotropic tensile properties imply that the deformation system of rolled AZT910 sheet consists of basal and non-basal slips at room temperature, and is a combination of basal slip, non-basal slip and grain boundary sliding/rotation (GBS) at 200 °C. The decrease of intensity and spreading of basal poles during tensile test and isotropic tensile properties indicates that GBS becomes the dominate deformation mechanism at 300 °C. The present work provides reference for the study of deformation behavior of novel superplastic magnesium alloy, and hence is of great significance for further application of wrought magnesium alloy.

1. Introduction

Magnesium alloy has attracted the attention of many researchers because of its lightweight, high fatigue limit and good recyclability. Mg-9Al-1Zn (AZ91) magnesium alloy has been widely used due to its good strength and castability [1]. However, there have been few reports about rolled AZ91 magnesium alloy due to its poor plastic formability at room temperature and some evident rolled edge cracking occurred even at elevated temperatures [2–4]. Nevertheless, AZ91 has a great potential as a superplastic material if massive uniformly distributed second phase and fine grains of ~5 μm could be achieved collectively [5]. It is generally accepted that grain size has a great influence on deformation behavior. Moreover, deformation mechanism of magnesium alloy depends on deformation temperatures. Generally, basal slip and twinning are the active deformation mechanisms at room temperature, but non-basal slip is also activated at temperatures higher than 200 °C [6,7]. However, grain boundary sliding/rotating (GBS) may become important at elevated temperatures [8,9].

It is widely believed that the limited number of active deformation systems in hexagonal-close-packed (*hcp*) metals such as magnesium alloy result in the formation of a strong crystallographic texture during mechanical processing. Recently, there has been substantial research on texture of magnesium alloy. Generally, intense basal texture is observed in rolled magnesium alloy, which has a great influence on tensile properties. Moreover, according to the reduction and strain paths of rolling, the basal pole figure is

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probably presented a tilt from the normal direction (ND) towards the rolling direction (RD) [10–12] or the transverse direction (TD) [10,13,14], which results in significant distinct mechanical properties in rolling plane. Ordinarily, tensile tests were carried out in a single direction, such as extrusion direction (ED) [15], RD or TD [16,17], while effects of tensile directions on deformation behavior, especially at high temperatures have not received much attention. Thus, it is of great importance to investigate the influence of tensile directions on deformation behavior and tensile properties of fine-grained Mg-9Al-1Zn-0.4Sn (AZT910) magnesium alloy at various temperatures.

In this work, the microstructure and texture, tensile properties of AZT910 rolled sheets during tension at room temperature, 200 and 300 °C were investigated by using three kinds of tensile specimens (rolling direction (RD), transverse direction (TD) and 45° towards RD). The purpose is to explore the effect of specified textures on deformation mechanisms of AZT910 at different temperatures, the role of second phase particles playing, as well as the evolution of second phase during superplastic deformation. The present work is of great significance for the further application of wrought magnesium alloy, and provides reference for the study of deformation behavior of superplastic magnesium alloy.

2. Experimental procedure

In the present work, the AZT910 cast ingot was extruded to 6.6 mm thickness plate with the extrusion ratio of 31 and then rolled to 0.9 mm sheet. Prior to rolling, the extruded material was cut into specimens of ~30 mm × 45 mm × 6.6 mm (width, length and thickness). The chemical composition of the AZT910 alloy measured by an optical spectrum analyzer (ARL 4460) is listed in Table 1. The addition of Sn is to improve the deformability of the alloys [18]. Firstly, the received plates were subjected to a multi-stage homogenization treatment including heating at 300 °C for 1 h, followed by heating up to 410 °C for 3 h and then air cooling to obtain a homogeneous microstructure and remove residual stress prior to rolling experiments. In the present investigation, the rolling direction remained unchanged during the whole rolling process with a rolling velocity of 12 m/min and the rolls were preheated to 100 °C. The rolling temperature was kept at 350 °C for the first 12 passes and 300 °C for the last 4 passes. Before each rolling pass, the rolled specimens were returned to the furnace and reheated for 5–15 min to regain the rolling temperature. After 16 passes, the sheets were rolled to a final thickness of 0.9 mm (the total thickness reduction was about 86.4%), followed by a heat treatment at 275 °C for 1.5 h.

The microstructure was characterized by field emission scanning electron microscopy (FESEM) and scanning electron microscopy (SEM). FESEM microstructures were obtained by using a JEOL JSM-6700F with an accelerating voltage of 8 kV and a current of 10 μA. SEM microstructures were observed by using a TESCAN VEGA 3 XMU, with an accelerating voltage of 20 kV and a current beam intensity of 10 μA. Electron backscattered diffraction (EBSD) analysis was conducted using a TESCAN VEGA 3 XMU SEM equipped with an Oxford Instruments NordlysNano EBSD detector using AZtec and Channel 5.0 software to collect and analyze data. EBSD characterization was performed with 20 kV acceleration voltage and 18 μA current beam intensity, 20 mm working distance, 70° tilt, and with 0.3–0.8 μm scan steps depending on the magnifications. To gain EBSD mapping, the samples were prepared by mechanical polishing, followed by electrolytic polishing at 20 V for 60 s in AC2 electrolyte. The average grain size was measured by the linear intercept method in accordance with ASTM standard E112-96 [19].

To evaluate tensile properties of the rolled AZT910 alloy, dog-bone shaped tensile specimens (10 mm gage length and 4 mm gage width) were machined from rolled sheets by electrical discharge machine. Meantime, to examine the mechanical properties in plane of the rolled sheets, uniaxial tension tests in the RD, TD and 45° towards RD (45RD) were carried out at room temperature, 200 and 300 °C, respectively. The schematic illustration of orientations of the three specimens and their dimensions are shown in Fig. 1. During performance testing, tensile tests were conducted until fracture using an INSTRON 1121 universal testing machine at room temperature and an INSTRON 5869 universal testing machine at 200 and 300 °C with a strain rate of $1.0 \times 10^{-3}\ s^{-1}$. The temperature of specimen was measured in the three-zone furnace after a 10 min soak at the testing temperature. Macrotexture of the samples were conducted on Panalytical X′ Pert Pro X-ray diffractometer using Cu K_α radiation at 40 kV and 40 mA. X-ray diffraction (XRD) data were obtained using a DX-2700B X-ray diffractometer with Cu K_α radiation at 40 kV and 30 mA and corrected for background using the Jade software.

3. Results and discussion

3.1. Microstructure and texture

As shown in Fig. 2a and b, the as-received extrusion AZT910 alloy after homogenization exhibits a microstructure consists of α-Mg matrix and $Mg_{17}Al_{12}$ intermetallic compound. It apparently shows that residual $Mg_{17}Al_{12}$ phase distributes along grain boundaries whereas a few in grain interiors. After homogenization treatment, the average grain size is ~26 μm (in Fig. 2d). The EBSD orientation map and corresponding microtexture of the as-homogenized sample are shown in Fig. 2c and e. Note that the grains exhibit relatively random orientations. Moreover, in addition to the strong basal texture there is a weak texture rotated from the basal plane towards the ED and TD, respectively.

It is evident that grains are greatly refined after 16-passes rolling (Fig. 3a), where equiaxed recrystallized grains are formed with an average size of ~5 μm (Fig. 3c). In addition, the $Mg_{17}Al_{12}$ particles are uniformly distributed along grain boundaries as well as in grain interiors. Note that the morphology of $Mg_{17}Al_{12}$ particles is almost spherical. In the present study, there existed almost no second phases such as $MgZn_2$, Mg_2Sn and Al_8Mn_5 precipitates other than $Mg_{17}Al_{12}$ due to the very low contents of Zn, Sn and Mn elements. It was reported that parts of Zn dissolved into α-Mg matrix existing in the form of solid solution [20] and a part of Zn substituted for Al in $Mg_{17}Al_{12}$ phase to form $Mg_{17}(Al, Zn)_{12}$ [21,22]. The addition of Sn probably forms a Mg_2Sn phase, which is hard to be observed because the formation of Mg_2Sn is prior to that of the $Mg_{17}Al_{12}$ phase which adheres to Mg_2Sn [23]. The addition of Mn element aims to remove harmful Fe during the melting process [24]. EBSD orientation map shown in Fig. 3b reveals that nearly all grains exhibit an intense basal plane orientation, i.e. their (0002) planes are almost parallel to the plane of the rolled sheet. From the (0002)

Table 1
The chemical composition of AZT910 magnesium alloy in weight percent.

Mg	Al	Zn	Sn	Mn	Si	Fe
Balance	8.81	0.73	0.43	0.25	0.01	0.005