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Microstructure and mechanical properties of AZ80-Ag alloy processed by hot ring rolling

Gang Zeng [a], Chuming Liu [a], Yonghao Gao [a,b,*], Shunong Jiang [a,c]

[a] School of Materials Science and Engineering, Central South University, Changsha 410083, China
[b] State Key Laboratory for Powder Metallurgy, Central South University, Changsha 410083, China
[c] School of Civil Engineering, Central South University, Changsha 410083, China

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ABSTRACT

Hot ring rolling (HRR), a near-net-shape technology, was used to fabricate a large sized AZ80-Ag alloy ring at 653 K in this study. The microstructure, texture and mechanical properties of different regions within the HRRed ring wall were systematically investigated. The lowest level of plastic deformation and highest temperature are identified in the central region of the ring wall. Due to the influence of non-uniform distribution of strain and temperature, the deformed microstructure is inhomogeneous throughout the ring wall thickness. After rolling deformation, the spherical β-$Mg_{17}Al_{12}$ precipitates are formed inside grains and along grain boundaries. The basal pole inclines and the {0001} orientation spreads towards some particular directions depending on the sampling regions. Therefore, obvious anisotropy of mechanical properties was observed in various regions due to different basal slip Schmid factors in the tensile directions.

1. Introduction

Ring rolling is an effective plastic deformation method to manufacture large seamless metal rings [1,2]. It is a near-net-shape technology that makes simultaneous diameter expansion and wall thickness thinning, thus reducing energy and material costs. Generally, the ring rolling can be classified into two types, i.e. radial-axial and radial ring rolling. The radial-axial type consisting of radial and axial rolling is preferred because the fishtail flaws in axial direction of the ring can be eliminated. At present, the large seamless rings, mainly made of steel and titanium alloys, are important components of aircraft, spacecraft and rocket. Compared with those traditional alloys, magnesium alloys are attractive and lightweight structural materials due to their low density, high specific strength and superior electromagnetic shielding performance [3–6]. Considering these advantages, large sized magnesium alloy rings have the potential to be widely used in the transportation and aerospace industries. Although magnesium alloy has an inferior plastic deformability at ambient temperature due to its hexagonal close-packed crystal structure, its plastic deformability can be remarkably improved when the deformation temperature is elevated to some degree [7–9], which is attributed to the enhancement of mobile basal and non-basal slip systems. Therefore, it is reasonable and innovative to manufacture large sized magnesium alloy rings by hot ring rolling (HRR) process.

During the past 50 years, published researches have been mainly dedicated to studying the effects of different process parameters, such as rotational speed, rolling force and feed rate [10,11], where the published papers in recent years are mainly about the finite element modeling (FEM) and simulation [12–15]. Those researches are mostly concentrated on the HRR process of relatively traditional alloys. However, few studies have been focused on investigating the microstructure and mechanical properties of the HRRed magnesium alloys.

In our previous study [16] the HRR process was used to fabricate an AZ80-Ag alloy ring at 673 K. That study paid much attention to the effects of aging treatment on the HRRed alloy while little has been investigated concerning the deformation strain distribution and resultant microstructure of the ring. Besides, the processing with a relatively high temperature (673 K) required considerable energy consumption, which is not beneficial to the large-scale practical fabrication. Therefore, the current research aims to demonstrate the feasibility of HRR processing on AZ80-Ag alloy at a lower deformation temperature (653 K) and examine the final properties of the HRRed specimens. The microstructure, texture and mechanical properties of the ring are analyzed.

* Corresponding author at: School of Materials Science and Engineering, Central South University, Changsha 410083, China.
E-mail address: gaoyonghao_009@163.com (Y. Gao).

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2. Experimental procedures

The material used in this study was semi-continuously casted AZ80-Ag (Mg-8.10Al-0.46Zn-0.18Mn-0.18Ag in wt%) alloy with a diameter of 450 mm. Prior to the HRR process, a large sized ring blank was fabricated as illustrated in [16], with an outer diameter (OD) of 555 mm, an inner diameter (ID) of 255 mm and a height of 470 mm.

The HRR process was conducted with a radial-axial ring rolling machine, the schematic diagram of which is shown in Fig. 1a. The details of the operation principle of this specific machine have been described in [16]. Prior to HRR, the idle roll was preheated to 573 K and the ring blank was kept at 653 K for 8 h to enhance its deformability and reduce the risk of cracking. The ring blank was rolled directly to a final size of 770 mm in the OD and 610 mm in the ID with a negligible change in the height. After HRR, the ring was immediately quenched in cold water to retain the deformed microstructure. Hereafter, RD, AD and ND denote rolling, axial and normal direction of the ring, respectively, as schematically shown in Fig. 1b.

The microstructure was examined using a Leica optical microscope (OM) and a Sirion200 field emission scanning electron microscope (SEM) equipped with an energy dispersive X-ray spectrometer (EDS). Samples for microstructure analysis were prepared by the conventional mechanical polishing and etching using a solution of oxalic acid (1 g), nitric acid (1 ml), acetic acid (1 ml) and distilled water (100 ml). The phase constitution was identified using a Rigaku D/Max2500 X-ray diffractometer. The crystal orientation was analyzed using electron backscatter diffraction (EBSD) at a step size of 2 μm on a Sirion200 SEM coupled with a TSL-OIM system. Samples for EBSD, with a dimension of 6 mm × 4 mm × 0.3 mm, were prepared by electric spark cutting, mechanical polishing and automatic twin-jet electro polishing using a solution of 60% methanol, 35% n-butyl alcohol and 5% perchloric acid at a potential of 30 V and 238 K. The samples for microstructure and texture investigation were selected from five regions along the ring wall thickness with the neighboring regions being approximately 20 mm apart, i.e. near the OD surface (region-NOD), 20 mm below the OD surface (region-BOD), in the center of the ring wall (region-IC), 20 mm below the ID surface (region-BID) and near the ID surface (region-NID), as illustrated in Fig. 1b.

Tensile tests were conducted at ambient temperature using an Instron 3369 testing machine under a cross-head speed of 1 mm/min. Tensile specimens with the gauge dimensions: Φ4 mm × 20 mm were machined from the region-NOD, region-IC and region-NID along their RD and AD. To ensure the reliability of the tests, the tensile strength reported in the work was averaged from three repeated tensile tests.

3. Results and discussion

3.1. Microstructure of the HRRed specimens

Fig. 2 exhibits the optical micrographs of different regions within the HRRed ring wall. The region-NID (Fig. 2a) is mainly comprised of equiaxed grains due to repeated rolling deformation and dynamic recrystallization. Besides, some second phase particles, characterized by black dots, are observed in both the grains and grain boundaries (Fig. 2a). An analogous "necklace" microstructure is revealed in the region-IC (Fig. 2c), where some large unrecrystallized grains are surrounded by smaller recrystallized grains. Meanwhile, a few second phase particles precipitate during HRR and may retard the growth of recrystallized grains [17,18]. In the region-NOD (Fig. 2e), a large number of recrystallized grains and precipitates are presented. Lots of recrystallized grains and several large undeformed grains are observed in the region-BID (Fig. 2b), which can be seen as the transition from the region-NID to region-IC in terms of recrystallization ratio. Similarly, the region-BOD, in which one of large undeformed grains is marked with a white circle (Fig. 2d), can be regarded as the transition from the region-NOD to region-IC.

The deformed microstructure exhibits different features throughout the ring wall thickness, which is usually related to the heterogeneous degree of plastic deformation [19]. When ring rolling process starts, plastic deformation is predicted to be initiated near the inner diameter followed by the initiation near the outer diameter and then penetrates into the central region of the ring wall, as described by Hua et al. [20]. This asymmetric deformation behavior may make the strain be as a function of sampling regions. Apart from the deformation strain, the temperature is believed to be another factor influencing the deformed microstructure [19]. Zeng et al. [16] have reported that during HRR the temperature distribution along the ring wall thickness tends to be: region-IC > region-NID > region-NOD. As we know, the deformation temperature and strain are two critical factors to control dynamic recrystallization. Even though the temperature is the highest in the region-IC, some deformed grains are insensitive to dynamic recrystallization (Fig. 2c). It can be reasonably deduced

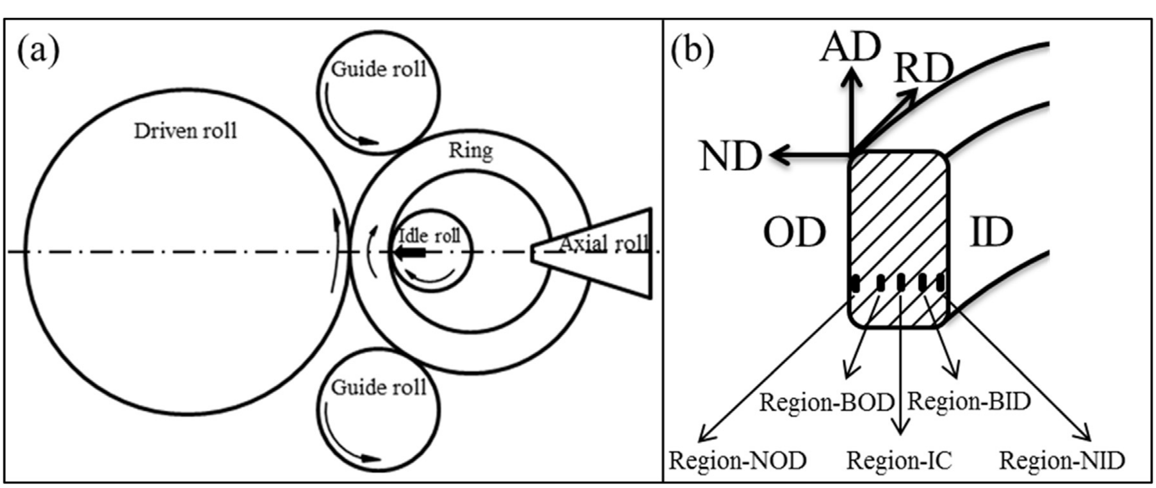

Fig. 1. (a) The schematic diagram of the hot radial-axial ring rolling. (b) The cross-section of the ring, definition of coordinate system and the investigated regions throughout the ring wall thickness.