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Dynamic recrystallization behaviors of a Mg-4Y-2Nd-0.2Zn-0.5Zr alloy and the resultant mechanical properties after hot compression

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ABSTRACT

The development behaviors of ultrafine grains (UFGs) due to continuous dynamic recrystallization (cDRX) were investigated in hot compression of a Mg-4Y-2Nd-0.2Zn-0.5Zr alloy pretreated in solution and subsequently peak-aging. In the aging sample containing statically precipitated particles (SPPs), the occurrence of cDRX starts to take place at medium to high strains, and finally a stable size of UFGs are fully developed in a whole volume. In the as-solution sample with no SPPs, by contrast, the size of UFGs evolved increases rapidly at lower strains, slowly at medium strains and then finally shows a bimodal distribution in high strain. In the latter, smaller grains accompanying with an incomplete formation of UFGs are developed by any effect of dynamically precipitated particles (DPPs). The microtexture evolved is effectively randomized in the regions of UFGs, leading to the formation of a weaker texture. The tensile elongation of the aging sample, with SPPs and fully developed UFGs, was around 17.4%. This was much higher than that of the as-solution one, with no SPPs and incompletely developed UFGs, that was 11.8%, which might result from the more randomized texture due to fully developed UFGs.

1. Introduction

Magnesium (Mg) alloys, known as the lightest structural materials, have been applied in modern aerospace, transportation and electronics industries, etc. [1,2], while the poor mechanical properties such as low formability limit their practical application as structure components. The poor mechanical properties as well as the development of strong basal texture in Mg alloys can be resulted from hexagonal close-pack structure and then limited number of slip systems [3]. The development of any texture weakening and some improvement of the formability of Mg alloys have attracted much interest of engineers and scholars by grain refinement taking place during various thermo-mechanical processes including mechanical alloying and sever plastic deformation [4,5,6]. It is known [2] that grain refinement in hot deformed magnesium alloys can be attained to reduce the basal texture. These SPD processes such as equal channel angular pressing (ECAP), accumulative roll bonding (ARB), high pressure torsion (HPT), however, are not simple enough for any application in practical production.

Recent demand for the development of higher strength Mg alloys has revived research interest on the strengthening effect of precipitation in Mg alloy [7,8,9]. Due to the high solubility of RE elements in Mg alloys at high temperature and their rapidly decrease with lowering temperature, Mg-RE alloys are expected to show remarkable age-hardening response during low temperature aging. For example, Su et al. [10] determined that high volume fraction of fine β′ precipitates can result in high mechanical properties.

But if we are to use Mg-RE alloys widely, combined properties of high strength and good formability are desired. Specifically, except the precipitates hardening effect, refined grains with weak basal texture are needed. Yu et al. [11] found that Mg_5RE precipitation particles lead to grain refinement as a result of particle pinning in a Mg-11Gd-1Nd-1.5Zn-0.5Zr. Besides, it has been reported in WE43 alloys [12] that dynamic precipitation occurred during hot deformation leads to the formation of $β_1$ precipitation particles. Some recent works on common Mg alloys have shown that precipitation particles have effective potential to refine the grain size and modify the texture through dynamic recrystallization affected by the characteristics of precipitation particles, such as the size, volume fraction, distributions, etc. [13,14,15]. However, for the Mg-RE alloys with Zn addition, the effects of precipitation particles on grain refinement and texture modification due to dynamic recrystallization behaviors have not been systematically investigated yet.

Therefore, a simple and practical processing, namely high-speed hot compression, was applied to refine the grains of a Mg-4Y-2Nd-0.2Zn-0.5Zr alloy in this study. The selected alloy has great potential to be used in aerospace industry due to its high strength and great creep resistant at room and elevated temperatures [16]. Mg-4Y-2Nd-0.2Zn-0.5Zr alloy contains large amounts of two kinds of precipitation

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particles, i.e. β″ (Mg_3RE) and β′ ($Mg_{12}YNd$), which exist stably at temperature as high as 520 °C [17]. By adopting suitable thermomechanical processes including aging treatment, these precipitates were fully developed before hot deformation. The present study was particularly intended to clarify any effect of precipitated conditions on grain refinement and the microtexture development in the present Mg alloy during high-speed hot compression.

2. Experimental procedure

The composition of the Mg alloy tested in the present study was melted in an electric resistance furnace under a protective atmosphere of CO_2 and SF_6 in ratio of 100:1. Alloying elements of Y, Nd, Zn and Zr were prepared from 99.9% Mg, 99.99% Zn and some master alloys of Mg-25%Y, Mg-25%Zr and Mg-30%Nd (wt%), respectively. After these alloying elements were completely dissolved, the melt was refined by flux and hold for 15 min at 720 °C to homogenize and cast into cylindrical ingots of 60 mm in diameter and 100 mm in height. The chemical composition of the ingot was finally determined as Mg-4Y-2Nd-0.2Zn-0.5Zr (wt%). The alloy ingots were cut into 12 mm × 10 mm × 10 mm rectangular samples and then solution treated at 525 °C for 10 h, and then quenched in water. These samples are hereafter named as the as-solution (AS) one. A part of them were aged at 220 °C in oil bath for various periods of time from 5 to 25 h in order to investigate the age hardening vs. time behavior (see Fig. 1). The samples preheated at a peak aging time of 20 h were denoted here as the as-aged (AA) one. These samples were compressed at temperatures ranging from 420 °C to 510 °C with a constant strain rate of 0.3 s^{-1} using an Inston-type mechanical testing machine. They were held for 5 min at each compression temperature and then compressed. In order to avoid any precipitation and static restoration process taking place during cooling, they were immediately quenched into water just after hot compression.

The microstructures evolved were observed by optical microscopy (OM), scanning electron microscopy (SEM) equipped with electron backscatter diffraction (EBSD) and transmission electron microscopy (TEM). For OM observation, the compressed samples were cut to thin plates with a thickness of 1 mm parallel to along the compression axis at the center and then mechanically polished and subsequently etched in an acetic picral solution, i.e. 2.1 g picric acid + 5 mL water + 5 mL acetic acid + 35 mL ethanol [18]. For SEM and TEM analysis, the samples compressed were punched into 3 mm in diameter and prepared with an ion milling method after mechanically grinded. The step size used for the EBSD scan was 0.8 μm. It should be mentioned that selected OM and EBSD images, though only small part of the sample, they generally reveal the main characterization of the whole sample and thus can be trusted and compared between different conditions. The constituent of precipitations were identified by Rigaku D/max 2550 X-ray diffraction with Cu Kα radiation. The Vickers hardness tests were carried out on each plate at room temperature under a load of 3 N with a 10 s duration, and 20 measurements were performed for each condition. Tensile samples with a gauge size of 6 mm × 1.5 mm × 1 mm were machined from deformed samples. Tensile test was performed at room temperature with a strain rate of 3×10^{-3} s^{-1} and three specimens were used for each testing condition in order to confirm the repeatability.

3. Results and discussion

3.1. Age-hardening behavior

Fig. 1 shows a hardness vs. aging time (MPa-t) curve and the microstructures in as-solution and after aging at 220 °C for the present Mg alloy. The hardness (MPa) increases continuously with aging time and approaches a peak value of about 840 MPa at t ≈ 20 h, followed by a rapid decrease due to over aging. The average grain sizes of the AS and AA samples were about 134 μm and 140 μm, respectively.

Fig. 2 shows a bright field TEM image and XRD pattern(s) for the peak-aged (i.e. AA) sample(s). It is seen in Fig. 2(a) that platelet-shaped precipitations, with a dimension of 30–50 nm in length and 2–5 nm in width, are densely dispersed. In addition, there are a few spherical precipitations with a diameter of about 8 nm. It is suggested by the XRD data and also some previous works [11,19] that the platelet-shaped precipitates may be DO19-β″ and the spherical ones be bco-β′, which

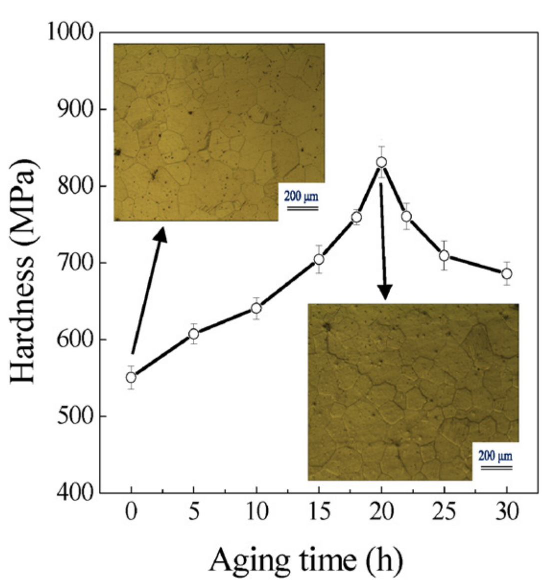

Fig. 1. Hardness curves and typical microstructures of Mg-4Y-2Nd-0.2Zn-0.5Zr alloy treated in solid solution and peak aging at 220 °C.

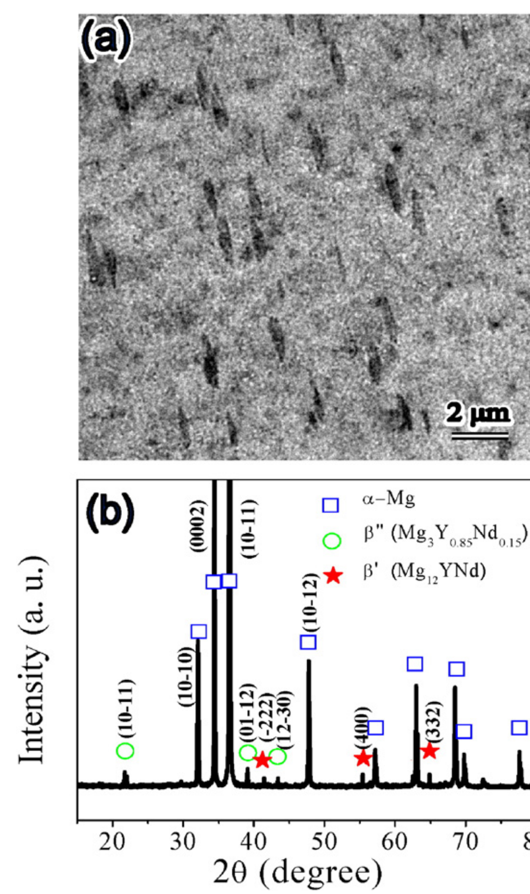

Fig. 2. (a) TEM image and (b) XRD patterns of the AA sample heated at 510 °C for 5 min before hot deformation.