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ARTICLE

Effect of Aging Treatment before Extrusion on Microstructure and Mechanical Properties of AZ80 Magnesium Alloy

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Abstract: This paper investigated the effect of aging treatment before extrusion on microstructure and mechanical properties of AZ80 magnesium alloy. Fractural microstructures of the test specimens were also analyzed by scanning electron microscopy. Results show that aging treatment before extrusion can remarkably promote grain refinement; the dispersed $Mg_{17}Al_{12}$ particles precipitated from the matrix during aging treatment before extrusion distribute in the grain boundaries; during the subsequent extrusion process these particles can pin grain boundaries migration and lead to fine microstructure; however, with prolonging the aging time, the grain refinement effect is weakened. After aging treatment and subsequent extrusion, the yield strength, tensile strength and elongation are increased. Based on fracture surface analysis, the premature cracks occur around big particles in grain boundaries lead to loss of elongation. The strengthening effect of aging before extrusion in AZ80 magnesium alloy proven in this paper provides a new method for the design of the relatively high-performance magnesium alloys.

Key words: magnesium alloy; recrystallization; microstructure; mechanical properties; Zener pinning effect

As the lightest structural materials, magnesium (Mg) alloys are widely used in the automotive, aeronautical and electronic industries for their light weight, high specific strength and specific stiffness, good castability and machinability, excellent damping properties and good electromagnetic shielding [1-3]. However, due to their poor mechanical properties, the applications of Mg alloys have been restricted. The poor mechanical properties of magnesium alloys result from the hexagonally close-packed structure (HCP), so it could not provide five independent slip systems uniform deformation requires at room temperature [4,5]. In order to improve the mechanical properties, many strengthening methods have been applied and studied to enhance the strength of magnesium alloys[6-9], such as heat treatment, pre-twinning, alloying and grain refinement. Although great efforts have been done, the mechanical properties of Mg alloys still cannot satisfy the needs of applications.

In order to enlarge the application field of magnesium alloys, the design of relatively high-performance wrought magnesium alloys has received much attention in recent years. The main reason is that wrought magnesium alloys often perform better mechanical properties than cast magnesium alloys because the deformation process can get rid of pores, homogenize composition and refine grains [10]. Mg-Al-Zn series alloys, one of the most commonly used wrought magnesium alloys including AZ31, AZ80 and AZ91, display good comprehensive mechanical properties and low cost. Among them, the AZ80 alloy has been the well-known commercial magnesium because it exhibits a good combination of medium strength, good corrosion resistance, excellent forging capability and lower price[6]. However, the AZ80 alloy still has some deficiencies that result in the limit

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of applications, such as the insufficient strength and poor ductility[11].

It is widely believed that fine grain strengthening is the most important method to improve both strength and ductility at the same time [12,13]. Controlling the grain size during thermomechanical processing is the key to improving the properties of wrought magnesium alloys[14]. As to control the grain size during hot deformation, using the stable pinning particles to pin the migration of grain boundaries and prevent grain growth has been a new method in recent years[15]. This mechanism is called Zener pinning effect. A great many works based on this mechanism have been carried out so far. Zener pinning effect that results in grain refinement in magnesium alloys during dynamic recrystallization (DRX) has been applied to pure Mg, AZ31 alloy, AZ61 alloy, AZ91 alloy and ZK60 alloy [16-20]. However, up to now, there are few researches on the Zener pining effect on AZ80. What's more, most of the precursory studies focus on revealing the mechanism of Zener pinning effect during hot deformation and pay more attrition to the Zener–Holloman parameter. Hence, in the present study, using the particles precipitating from supersaturated solid solution during aging treatment before extrusion is the key point to refine grain using Zener pinning effect. Aging treatment was carried out before extrusion so that more particles precipitated from matrix during aging and the precipitates pinned grain boundaries migration and prevented grain growth due to Zener pinning effect. In consequence, the effect of aging treatment before extrusion on microstructure and mechanical properties of AZ80 magnesium alloy was investigated.

1 Experiment

The material used in the present study was the cast billets of commercial AZ80 magnesium alloy. The chemical composition was confirmed by X-ray fluorescence spectrometer (Shimadzu XRF1800) and the results are shown in Table 1. In order to remove macrosegregation and form supersaturated solid solution, the ingots were homogenized at 420 °C for 24 h and then quenched in hot water (~90 °C). After that the quenched alloys were aged at different status to form various precipitates before extrusion. Generally, the discontinuous precipitation would happen in the AZ80 alloy when the aging temperature is below 250 °C and continuous precipitation would happen when the aging time exceeds 310 °C. Hence, aging at 180 °C and 330 °C were conducted in the present study. According to the study of aging process for AZ80[8], the peak hardness would appear after aging for 10 h. However, with aging time increasing to 30 h, the aging hardness would decrease. It is demonstrated that more precipitates precipitate from the matrix when the aging time exceeds 10 h and overaging happens when the aging time exceeds 30 h. Therefore, the process selections of aging at 180 °C for 12 h, 180 °C for 48 h and 330 °C for 48 h are regarded as the aging process of discontinuous and peak-aged, discontinuous and overaged, continuous and overaged, respectively. An AZ80 sample without aging treatment before extrusion was also used in these experiments for comparison. The detailed heat treatment schedule is given in Table 2. For the sake of refining the microstructure, the comparison alloy and aged samples were hot extruded to bars with the diameter of 16 mm at 330 °C with the extrusion ratio of 25:1 at a ram speed of 1 mm·s^{-1}. Both the comparison and as-aged samples were pre-heated at 330 °C for 1 h before extrusion.

Table 1 Chemical composition of AZ80 alloys (wt%)

Elements	Mg	Al	Zn	Mn
Content	90.75	8.40	0.66	0.19

The microstructures of the samples before and after extrusion were observed by an optical microscope (OM, OLYMPUS OLS4000). The precipitates evolution of diverse heat treatment states was examined by a scanning electron microscope (TESCAN VEGA 3 LMH SEM) (SEM). After extrusion, uniaxial tensile tests were performed on a SANS CMT-5105 electronic testing machine at the strain rate of 2×10^{-3} s^{-1} at room temperature. The specimens for tensile tests were smooth dog bone-shaped with a gauge size of 5 mm in diameter and 35 mm in length and machined from the as-extruded bars under different heat treatment conditions. The tensile direction was parallel to the extrusion direction and the yield stress was determined as the 0.2% offset. Three tensile specimens were prepared for each condition and the average value was adopted. Afterwards, the fracture images of the tensile specimens were characterized by scanning electron microscopy (TESCAN VEGA 3 LMH SEM).

2 Results and Discussion

2.1 Microstructure before extrusion

Optical microstructure changes of AZ80 alloys under different conditions before extrusion are shown in Fig. 1. It should be noted that the grain size of the specimens subjected to aging treatment is a little bit larger than that of the comparison one. Except for that, there is no obvious difference among the specimens in various states. Fig.2 depicts the SEM morphologies of the AZ80 under different conditions before extrusion. As is shown in Fig.2a, few precipitates can be found in the specimen without aging treatment. After aging treatment, large quantities of second phases precipitate from supersaturated solid solution specimens. These precipitates

Table 2 Heat treatment process for the extruded AZ80 alloy

Designation	Heat treatment process
H1	ST[a] at 420 °C/ 6 h, WQ[b]
H2	ST at 420 °C/6 h, WQ, aging at 180 °C/12 h
H3	ST at 420 °C /6 h, WQ, aging at 180 °C/48 h
H4	ST at 420 °C /6 h, WQ, aging at 330 °C/48 h

[a] ST, solution treated; [b] WQ, water quenched