Effect of grain size refinement on microstructure and mechanical properties of AZ31 magnesium alloy

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Abstract. In this paper, microstructure and mechanical properties of ultra-grain size and coarse-grain size bulk AZ31 magnesium alloy were evaluated using tensile testing. The ultra-grain size (200nm) bulk AZ31 magnesium alloy showed well mechanical properties with stronger tensile strength (315MPa), typical ductile fracture surface and deep dimples, which can be attributed to grain size refinement of bulk AZ31 magnesium alloy.

1. Introduction

Magnesium and magnesium alloy have attracted many attentions for structure applications in a series of communities such as aerospace, automotive and 3C products, because of their lightweight, high specific strength and easy to recycle [1-3]. However, mechanical property of magnesium alloy at room temperature is very poor due to its hexagonal close packed (HCP) structure, which is an intrinsic drawback limiting application [4-5]. So, enhancing mechanical property of magnesium alloy is the key to expand its application [6].

Grain size refinement is a general way to improve mechanical properties of magnesium alloys and nanocrystalline material may exhibit different physic-chemical properties comparing to the same material with coarse grain size [7-9]. Various methods are available to prepare nanocrystalline material such as mechanical alloying, ECAE, ECAP and so on [10-12]. However, due to serve plastic deformation cannot refine the grain size of magnesium and magnesium alloys to nanometer level, so mechanical alloying of magnesium-based alloys has been widely studied in recent years [13-15]. Mechanical alloying is a solid powder plastic processing method, involving repeated welding, fracture and re-welding under high-energy ball milling equipment [16-17]. It is a simple and effective method to prepare a large number of ultra-fine grain materials, which has aroused extensive practical interest.

In this study, we prepared ultra-grain size AZ31 magnesium alloy powder with grain diameter no more than 50nm by mechanical alloying. Hot isostatic pressing (HIP) had been taken to densify nano-grain size and coarse-grain size AZ31 magnesium alloy powders. Finally, bulk AZ31 magnesium alloy with ultra-grain size (200nm) and coarse-grain size were obtained. The effect of grain refinement on the mechanical properties of bulk AZ31 magnesium alloy was further investigated.
2. Experimental procedures
Commercially available AZ31 magnesium alloy powders were used as raw material. The powders were divided into two parts (part A and part B). The magnesium alloy powders in part A were used for mechanical alloying, in this paper, the experiment was performed in PM 400 high energy ball milling. The ball milling process was carried out under argon atmosphere at room temperature. The initial mass ratio of ball to powder was 50:1 and the ball milling rotation speed was 400rpm. Cooling system was used to keep container temperature close to room temperature.

AZ31 magnesium alloy powders after mechanical alloying were taken hot isostatic pressing at 300°C, and then bulk sample with 50mm diameter and 80mm length was annealed at 300°C for 1h. The annealed bulk samples were finally machined into tensile test samples with 12mm diameter and 60mm gauge length. The above operation was also taken for commercial AZ31 magnesium alloy in part B for contrast testing. The dimensional drawing of tensile sample was shown in Figure 1 and tensile test was carried out by using an Instron 8801 testing machine at an initial strain rate of 10⁻³s⁻¹ until failure and the fracture surfaces were observed by SEM.

![Figure 1. The dimensional drawing of tensile specimen.](image1)

The grain size of bulk AZ31 magnesium alloy after hot isostatic pressing was observed by TEM. TEM films were prepared in 20 vol.% nitric acid and 80 vol.% methanol by standard electrolytic double jet polishing technique. TEM observation was carried out on Hitachi h8000 under 200 kV accelerating voltage.

3. Results and discussion
3.1. TEM observation
Figure 2 shows TEM pattern of bulk AZ31 magnesium alloy after mechanical alloying prepared by hot isostatic pressing at 300°C. The grain size was observed to be about 200nm which was agreement with the previously reported value of ultra-grain material [18-19]. So, TEM result shows that bulk AZ31 magnesium alloy after mechanical alloying and hot isostatic pressing has ultra-grain structure and is still ultra-grain size material.

![Figure 2. TEM pattern of AZ31 magnesium alloy after mechanical alloying](image2)
3.2. Stress-strain curves

Typical stress-strain curves of bulk AZ31 magnesium alloy with ultra-grain size and coarse-grain size obtained by hot isostatic pressing were illustrated in Figure 3, which were taken at 300°C with an initial strain rate of 1.0×10^{-3}s^{-1}. For this study, both stress-strain curves can be divided into two regions according to their different slopes. Region I of ultra-grain size and coarse-grain size of bulk AZ31 magnesium alloy show elastic deformation stage with linear elastic behavior. There is no near-plateau stage because of bad deformation of magnesium alloy at room temperature. Region II of two different grain size AZ31 magnesium alloys are the hardening stage and tensile strength of ultra-grain size and coarse-grain size bulk AZ31 magnesium alloy are tested to 315MPa and 155MPa, respectively. The improved higher tensile strength of ultra-grain size bulk AZ31 magnesium alloy is attributed to higher dislocation density. Therefore, grain size refinement of bulk AZ31 magnesium alloy appears to be responsible for their improved strength mechanical properties.

![Figure 3. Typical stress-strain curves of bulk AZ31 magnesium alloy. (a) ultra-grain size; (b) coarse-grain size](image)

3.3. Tensile fracture surface

Figure 4 presents tensile-ruptured surfaces of coarse-grain size and ultra-grain size bulk AZ31 magnesium alloy. On the fracture surface of coarse-grain size alloy, dimples are shallow and round (Figure 4a). The ultra-grain size alloy also shows typical ductile fracture surface, but dimples are deeper and more polygonal than coarse-grain size alloy (Figure 4b). These observation results due to the improvement mechanical properties of ultra-grain size bulk AZ31 magnesium alloy. So grain size refinement is an effective way to improve mechanical strength of magnesium alloys materials.
Figure 4. Tensile-ruptured surfaces of bulk AZ31 magnesium alloy. (a) coarse-grain size; (b) ultra-grain size

4. Conclusion
Based on extensive and careful examination, the following conclusions can be drawn.

(1) The grain size of bulk AZ31 magnesium alloy after mechanical alloying obtained by hot isostatic pressing at 300°C is below 200nm without dramatically growing up.

(2) The tensile testing shows tensile strength increased from 115MPa to 315MPa due to higher dislocation density in ultra-grain size bulk AZ31 magnesium alloy.

(3) The ultra-grain size alloy also shows typical ductile fracture surface, but dimples are deeper and more polygonal than coarse-grain size alloy

(4) The improvements in mechanical properties can be attributed mainly to grain size refinement.

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