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# The effect of precipitation on the mechanical properties of extruded AZ80

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**Abstract**

The effect of ageing temperature and time on precipitates in AZ80 magnesium alloy were studied by optical microscopy to investigate the influence on mechanical properties. The results show the precipitation is distributed as bands along the extrusion direction, with no twinning. After ageing, the precipitation becomes dispersed uniformly. When ageing at 423 K, discontinuous precipitated phase increases the yield and tensile strength but reduces the ductility of the material. For ageing at 573 K, with increasing the ageing time, static ductility first increases and then decreases. This means that recrystallization induced by continuous precipitation is beneficial to both the strength and ductility. However, the effect of age hardening under 573 K is not better than 423 K. And $\{10\bar{1}2\}<\bar{1}011>$ twinning was also activated in compression much more than in tensile samples, which is consistent with the behaviour of AZ31.

## Introduction

Magnesium alloys are considered as potential candidates for numerous applications, especially in transportation vehicles or lightweight enclosures for computer products owing to their excellent properties, such as low density, high strength-to-weigh ratios and high recycle-ability[1-2]. The Mg-Al-Zn is the most widely used magnesium alloy at present. Some studies on AZ80 have been reported on its microstructure and mechanical properties at different ageing temperatures [3-7]. However, the AZ80 alloy still has some drawbacks, such as poor ductility, low thermal conductivity and resistivity for example. The Mg-Al-Zn alloy usually contains large amounts of a coarse and network $\beta$-$Mg_{17}Al_{12}$ as a divorced eutectic distributed along the grain boundaries [8]. The network distributing of $\beta$ will restrict the deformation and interfere with slip transfer. According to the Orowan theory, the existing of $\beta$ phase which block the movement of dislocation can change the critical resolved shear stress (CRSS) of the slip systems. In the literature [9], it is considered that continuous precipitation is responsible for most of the age-hardening in Mg-Al-based alloys which is not the same as in this study.

So to further understand this alloy, the objective of this work is to investigate the effect of precipitation on the mechanical properties of AZ80 and the microstructure present during the yield stage to obtain a better understanding of how twinning affects deformation.

## Experimental

The material used in the present study was a commercial AZ80 alloy with the measured composition (wt. %): 8.3Al, 0.6Zn, 0.5 Mn, 0.002 Cu, Mg (balance). The as-cast ingot was homogenized at 683 K for 12h and extruded at 593 K with an extrusion ratio of 8 and an extrusion rate 4.2 $s^{-1}$ then air cooled. To clarify the precipitation behavior of this alloy, the material was then aged at either 423 K or 573 K for varying times. During ageing, the $\beta$ phase precipitated out in two forms: discontinuous and continuous precipitations. Mechanical tests were conducted at room temperature with an initial strain rate of $2.67\times10^{-3}$ $s^{-1}$ on a CSS-4410 testing machine. Optical microstructural characterization was conducted using an OLYMPUS-BXD60M microscope. Specimens for microstructure observation were grinded and electrolytic polishing before etching for 5 s in a solution of 5 ml acetic acid, 1.5 g picric acid, 10 ml distilled water and 25ml ethanol.

## Results and discussion

Figure 1 shows the as-extruded microstructure with no twinning from a plane parallel to the extrusion direction (ED). During deformation, the original grains are refined, and their boundaries become serrated and in addition subgrains are formed.

Recrystallization is complete and the average grain size after extrusion is 27.04 μm. For magnesium alloys, which have low stacking fault energy, the activation of dislocation cross slip and climbing is not easy. Grain refinement could be attributed to continuous dynamic recrystallization which involves a progressive increase in grain boundary misorientation and changes of low angle boundaries into high angle boundaries [10]. For extrusion temperatures are high enough that non-basal slip is active then twinning is not observed. The as-cast alloy contains a microstructure consisting of α-Mg matrix, and eutectic β-$Mg_{17}Al_{12}$. The precipitated phase was broken up and distributed as bands along the ED on the grain boundaries. Because the atomic mismatch and more imperfections than those of the grain interior, and the grain boundary energy is high, the β-$Mg_{17}Al_{12}$ phase is apt to nucleate and grow along the grain boundaries.

After ageing, no matter discontinuous at 423 K or continuous at 573 K precipitation disperse but still on the boundaries. The morphology of precipitate at 573 K is not the same as samples ageing after solid solution. Duly [11] states that at high temperatures, discontinuous precipitation disappears both because volume diffusion prevents its growth and because its nucleation becomes difficult. Clark [12] had reported that the continuous precipitation consists of relatively large plates on the basal of the matrix. They have certain orientation relationship in literature [13-15]. However, in Wei Tang's [3] work, they clarified the discontinuous precipitation with a lamella structure which has different shape and distributing have the same orientation with the matrix comparing to the continuous precipitation. That means the orientation between the matrix and precipitate has no relationship with the latter mechanical behaviors.

Figure 2 shows the yield and ultimate strength of AZ80 after ageing at 423 K which can be compared to that after ageing at 573 K. The results show a very distinct trend and almost the same for the yield stress at the two temperatures with time. When ageing at 423 K, the yield stresses for either tension or compression both increases with increasing time. However, ageing at 573 K, the yield stress didn't increase significantly in tension, but decreased dramatically in compression. We also observed that ageing didn't affect the ultimate strength at either ageing temperature.

When ageing at higher temperature, the yield stress increases slightly whereas the ultimate strength decreases. One reason is that under high temperature, supersaturation of Al element is low which affects the volume fraction of β. Another main reason for the poor ageing hardness response of AZ80 alloy has been attributed to the orientation and coarseness of the continuous precipitation that makes them inefficient obstacles to dislocation movement. Slip in magnesium, like most hcp metals, occurs predominantly on the close-packed basal planes (0001). Since the continuous precipitation consists of coarsely dispersed plates lying parallel to the basal plane, there are many opportunities for dislocation to glide between the precipitates [9]. On the other hand, discontinuous precipitation can effectively prevent the activation of twinning and the movement of dislocations, this is responsible for the increase in strength.

Figure 4 and Figure 5 shows that the ageing temperature has a different impact on the static toughness and uniform strain. They all exhibited different trends under different temperatures. The static toughness and uniform strain for ageing at 423 K decrease continuously while they decreased initially and then increased for ageing at 573 K. With further ageing, the volume fraction of β-$Mg_{17}Al_{12}$ phase on the grain boundaries increases, which is an obstacle to the movement of dislocation. This leads to dislocations pile-ups and this enhances the stress concentration resulting in microcracking.

Microstructures after ageing at 423 K for 24h having been strained 2% in either tension or compressive testing are showed in Figure 6. It can be seen that twinning occurred in the mechanical testing of aged samples. For processing by traditional extrusion, the texture can be roughly considered as having a fiber texture with the basal planes parallel to the extrusion direction. It is well known that Mg and its alloys are low-symmetry materials with hexagonal-close packed (hcp) structures that have axial ratios (c/a) of around 1.633 which is less than $\sqrt{3}$. This pattern of texture does not allow any twinning under tensile loading but maximum twinning under compressive loading. Therefore, this starting texture could activate the $\{10\bar{1}2\}$ twinning at a low degree of deformation. The other reason maybe twinning and precipitation both have a certain relationship with the α-Mg matrix, they two must have interaction on each other. The pattern of twinning is $\{10\bar{1}2\}<\bar{1}011>$ which occurred much more in compression than in tension, this is the same result as observed in AZ31. Chengling

Lv [16] also found the same phenomenon. Twinning nucleated from the interface of the precipitation. From observations of the same region before and after deformation, the edge of precipitated phase is broken which is the spreading of the crack. That's because the matrix and the precipitated phase which have different structure are not sensitive resemblancely to the applied stress.

**Conclusions**

Ageing treatment with different times at either 423 K or 573 K have been applied to the extruded AZ80 alloy, aimed at investigating the effect of heat treatment on the mechanical properties and the presence of twinning during tensile and compressive testing at room temperature. The following conclusions have been made:

(1) The ageing temperature plays an important role in the precipitating of β such that continuous precipitation occurs in 573 K, and discontinuous precipitation occurs at 423 K.

(2) The material exhibits different trends of mechanical properties. And precipitation strengthening doesn't work in this study. Discontinuous precipitation is responsible for the age-hardening in this study which is different to that observed in former published work.

(3) Twinning is activated during compression at room temperature of hot extruded AZ80 alloy after ageing at 423 K since the existing sharp fiber texture favored the activation of $\{10\bar{1}2\}$ twinning which is the same result as in AZ31 alloy.

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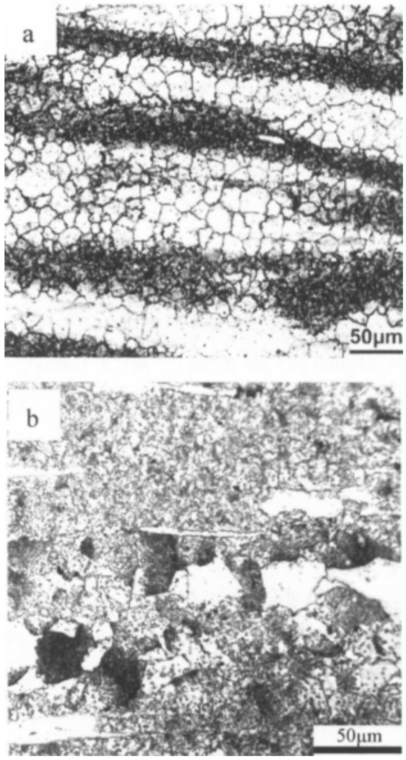
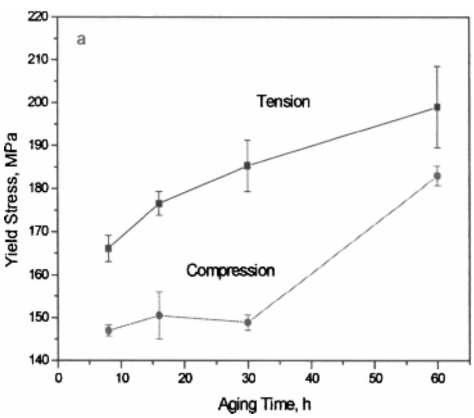



Figure 1. Optical microstructures of the cross section of AZ80 alloy after extrusion

(a) after extrusion (b) morphology of the continuous of the precipitated phase after extrusion



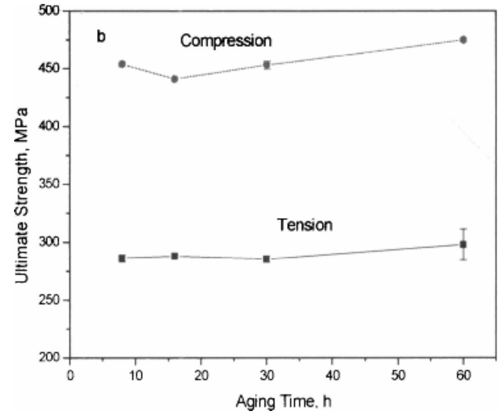




Figure 2. Yield (a) and ultimate strength (b) of AZ80 alloy ageing at 423 K

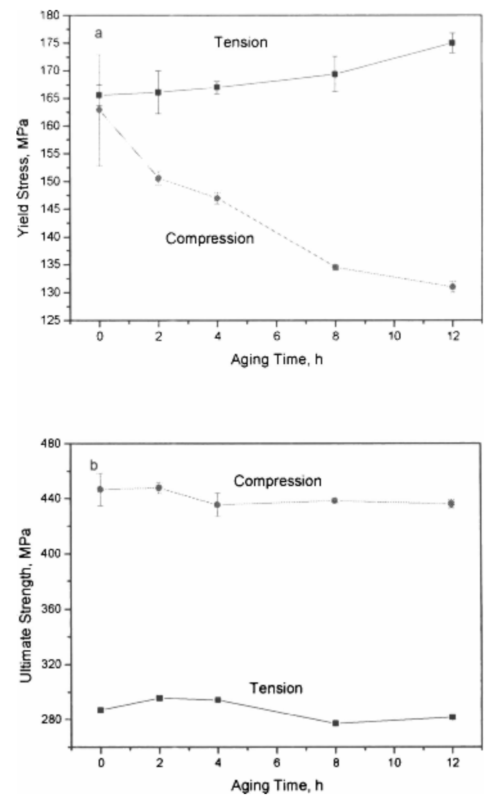



Figure 3. Yield stress (a) and ultimate strength (b) of AZ80 alloy ageing at 573 K

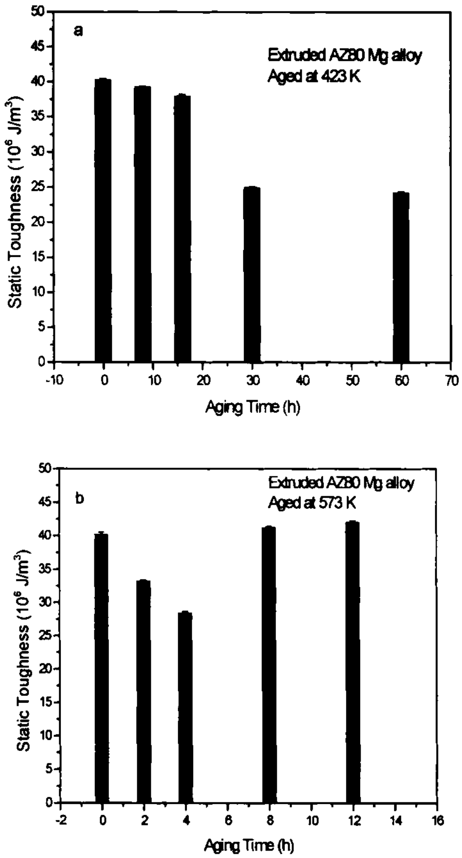
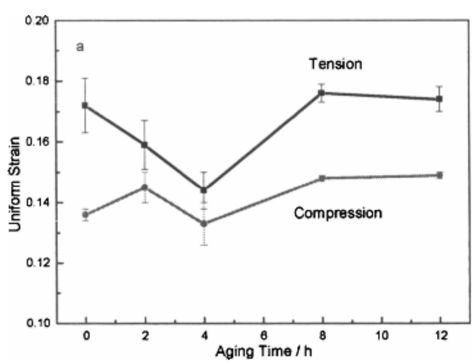



Figure 4. Static toughness of AZ80 alloy ageing at 423K (a) and 573 K (b)



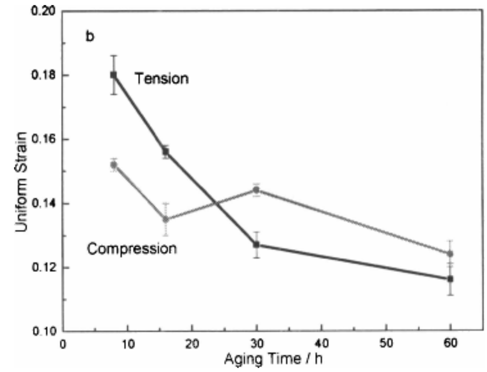




Figure 5. Uniform plastic deformation at 423 K (a) and 573 K (b) with different ageing time on extruded AZ80 alloy

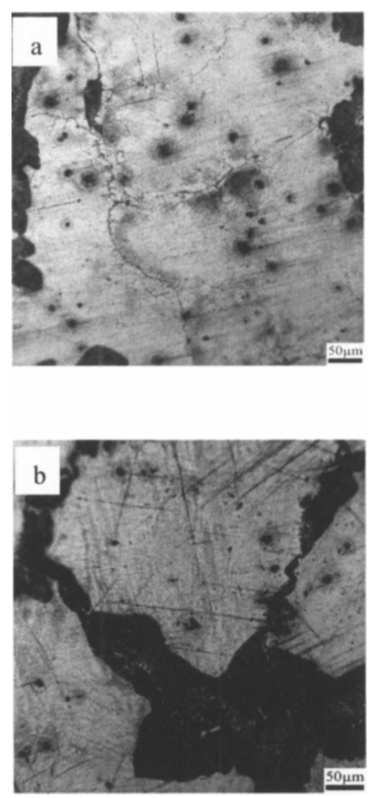



Figure 6. Microstructure of extruded AZ80 alloy with a strain of 2% for tension (a) and compressive (b)