Magnesium Technology 2013
Edited by: Norbert Hort, Suveen N. Mathaudhu, Neale R. Neelameggham, and Martyn Alderman
TMS (The Minerals, Metals & Materials Society), 2013

Magnesium Technology 2013

Texture and Twinning

Magnesium Technology 2013
Edited by: Norbert Hort, Suveen N. Mathaudhu, Neale R. Neelameggham, and Martyn Alderman
TMS (The Minerals, Metals & Materials Society), 2013

Effect of grain size and basal texture on tensile properties and fracture characteristics of extruded AZ31 alloy

Hsiang-Ching Chen, Truan-Sheng Lui, and Li-Hui Chen

Department of Materials Science and Engineering, National Cheng Kung University, Tainan, TAIWAN 701

With different tilting angles corresponding to the basal planes of the extruded Mg-3%Al-1%Zn alloy (0˚, 30˚, 45˚, 60˚, 90˚), uniaxial tensile tests of the extruded alloy were conducted at room temperature to discuss the effects of basal texture and grain size on its tensile properties and fracture characteristics. Compared to the coarse-grained sample, the fine-grained sample showed obvious increase in the yield stress since the tilting angles were 0˚ and 90˚. However, the total elongation of the fine-grained sample was higher than that of the coarse-grained specimen since the tilting angles ranged from 30˚ to 60˚. According to the observation of fracture surface, a dimple feature was observed in the fine-grained samples. In the contrast, a plate-like feature was recognized on the fracture surface of the sample with coarse grains.

Keywords: AZ31 Mg alloy, tilting angle, grain size, tensile mechanical properties

1. Introduction

Magnesium alloys are regarded as poor formability due to their limited available slip systems at room temperature. Because the magnesium is hexagonal close packed (HCP) crystal structure, the c/a ratio is about 1.624. The previous experimental study [1], the tensile ductility of extruded Mg alloy at room temperature is rather poor due to its (0002) basal plane parallel to the extrusion direction, which is not beneficial to inhibit the occurrence of deformation twins. In general, the formability of AZ31 Mg alloy, twinning is an important in keeping strain compatibility, especially when strained at room temperature. The two twinning systems {10-12}<-1011> and {10-11}<10-1-2> are anticipated in Mg alloy, the former is named as tension twin that is associated with tensile loading along the c-axis, and the latter is named as compression twin that corresponds to compressive loading along the c-axis[2-4].

In this study, the main aim is to discuss the deformation behavior of extruded AZ31 of different grain size and different c-axis tilting angles with tensile direction. Meanwhile, the influence of fracture surface and the microstructure of specimens deformed on the tensile ductility is investigated as well.

2. Experimental procedures

AZ31 Mg alloy with nominal chemical composition of Mg-3.26 mass% Al-0.6 mass% Zn- 0.6 mass% Mn is selected in this investigation as shown in Table1. An as-received billet with above-mentioned composition is extruded to 6-mm thickness and 350-mm width, this as-fabricated plate is machined to the dimension. The extruded plate has grain size of coarse condition due to choose the different temperature during extruded process, also has fine grain size in the extruded plate. In this study, the grain size and basal texture are recognized that on tensile properties and fracture characteristics of extruded AZ31 alloy. The coarse grain of extruded AZ31 is named as EX-1 and the fine grain of extruded AZ31 as

EX-2 in the following content.

Table 1 Chemical composition of AZ31 alloy.

	Al	Zn	Mn	Mg
mass %	3.26	0.58	0.61	Bal.

Microstructure samples for optical microscopy are polished and then etch with a solution of 4.2 g picric acid, 70 mL ethanol, 5 mL acetic acid and 5 mL water. The information of texture and precipitation of the particles is identified by X-ray diffraction spectra.

The tensile specimens are machined to tensile specimens shown in Fig. 1. The tensile tests with different tilting angles (0˚, 30˚, 45˚, 60˚, 90˚) corresponding to the c-axis of the extruded AZ31. In this study, tensile tests of the specimens are performed at an initial strain rate of $1.67\times10^{-3}s^{-1}$ at room temperature. All tensile data are obtained from more than 3 samples.

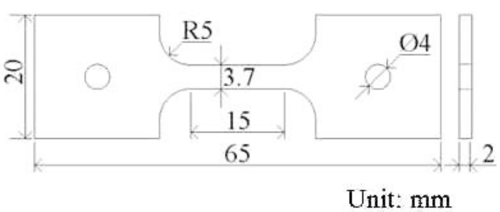

Fig.1 Schematic illustration of the dimensions of tensile specimens.

3. Results and discussion

The microstructure of EX-1 is shown in Fig.2, and that tend to coarse grain size. The average grain size of EX-1 is 184 μm. The average grain size of EX-2 is 13μm (see in Fig. 3).

X-ray diffraction patterns of the normal direction (ND) and transverse direction (TD) are demonstrated in Fig. 4(a) and 4(b) for EX-1 and EX-2 respectively. The result of the TD section in EX-1 and EX-2 are exhibit high (0002) intensity while the ND section indicates higher (10-10) and (10-11) intensity. The extruded possesses a texture in which (0002) basal plane is tended to align parallel to the extrusion direction (ED) and c-axis tend to align parallel to TD.

It is obvious that the grain size of the EX-2(13μm) is great smaller than EX3 as in Fig.2. The yield stress is reciprocal of the square root of the grain size from the Hall-Petch relationship $\sigma y = \sigma y0 + kyd-1/2$, where $\sigma y0$ is the resistance of the lattice to dislocation motion or regarded as the yield stress of the single crystal, and ky is a strengthening coefficient relevant to the difficulty to slip across the grain. The empirical relationship is constructed in Fig.5(a) to deduce the grain size dependence of yield stress. It can be seen that the tensile stress of EX-1 with tensile direction parallel with TD (tilting angle 0˚, EX-1- 0˚) is remarkable lower than of EX-2, and the values of EX-1 and EX-2 become similar at the tilting angle 30˚, 45˚and 60˚.

It is suggested by Armstrong [5] that σ_{y0} is effected by the critical resolved shear stress of the most easily initialized slip system and k_y is related to the critical resolved shear stress of the most difficulty initialized slip system or the twinning system for the metal with the Hexagonal Close Packed (HCP) crystal structure. The expression can be corrected as the following: $\sigma_y = M\tau_c + Mk_s d^{-1/2}$, where M is Taylor orientation factor, τ_c is critical resolved shear stress of the single crystal, k_s is a constant of the shear stress. The Hall-Petch relationship for the grain size and the yield stress of Mg alloy needs to be modified due to the anisotropy of the materials.

The microstructures of the tensile specimens deformed exhibit a lot of twin with tilting angles 0˚ shown as Fig.5(b). On the other hand, it is found that the deformation twins in the specimens of other tilting angle only can be observed in a few coarse grains

(Fig.6 and Fig.7). But EX-1-0˚ of yield stress is lowest (Fig.5(a)). This suggests the possibility that coarse grains structure of extruded AZ31 may in fact have low yield strength of the EX-1-0˚ by some as yet unknown mechanism.

The results of the tensile test with tilting angles 0˚ are shown that fine grain is no great favor of the elongation on tensile test as Fig.5(b). The better elongation can be acquired on tensile test while (0002) basal plane non-parallel to tensile direction, therefore the basal slip system and/or twinning system will contribute to the increase of tensile flow elongation [6,7]. Furthermore, extruded AZ31 of fine grain characterize anisotropic condition on elongation, but no remarkable changes to the coarse grain. The fracture surface of EX-1 and EX-2 characteristic are respectively shown as Fig.8 and Fig.9. The results of the tilting angle 0˚ exhibit the form of plate-like and the microvoids. The other tilting angles (30˚, 45˚, 60˚) of EX-1 obviously observe that plate-like characteristic in Fig.8 suggest that fracture either along twin boundaries or shear bands in this coarse grain of AZ31 alloys. The deformation microstructure of EX-2 have exhibit few plate-like structure to the brittle fracture with tilting angles 30˚、45˚and 60˚, and the microstructure various parts shows ductile fractures on dimple structures in Fig.9. This fine grain of AZ31 alloys suggest that fracture can increase elongation with tilting angles 30˚、45˚and 60˚.

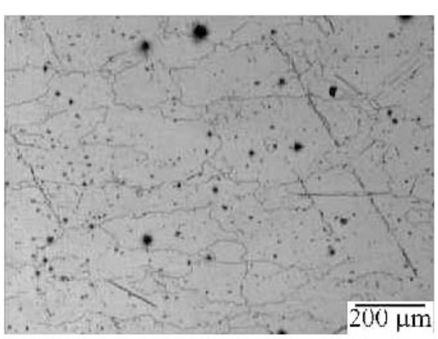

Fig.2 The microstructure of EX-1, the average grain size of EX-1 is 184 μm.

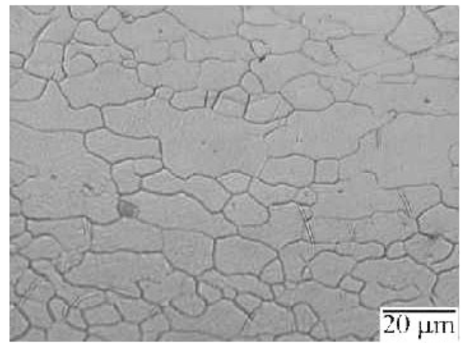

Fig.3 The microstructure of EX-2, the average grain size of EX-2 is 13μm.

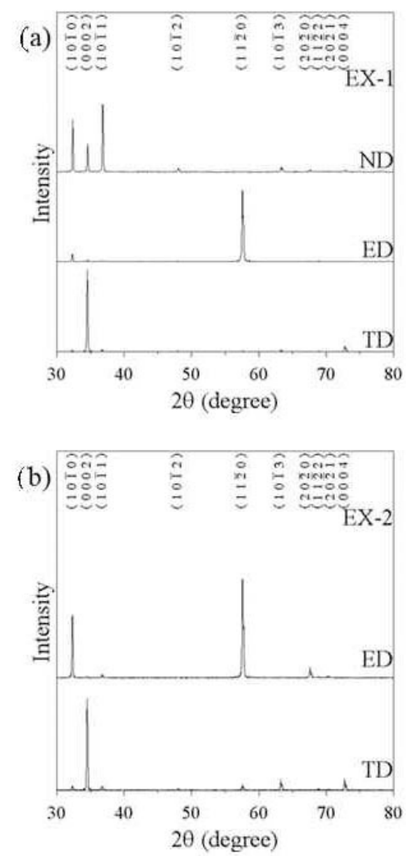

Fig.4 X-ray diffraction patterns : (a) EX-1, (b)EX-2.

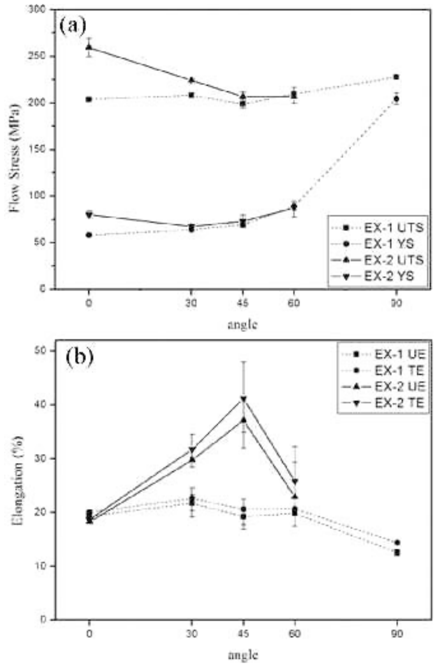

Fig.5 The tensile properties of EX-1 and EX-2: (a)flow stress, (b)elongation.

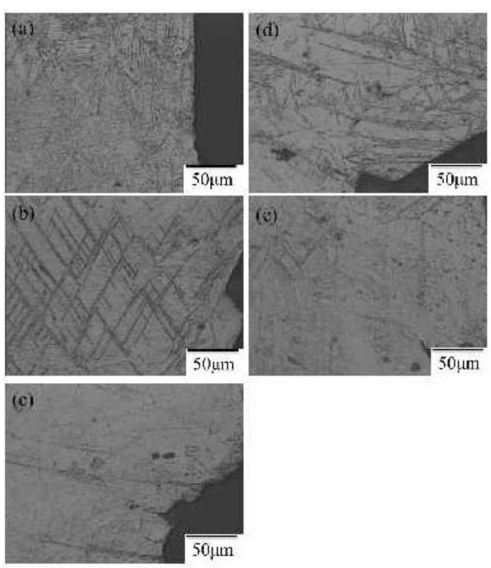

Fig.6 Deformation microstructures of EX-1 with different tilting angle:(a) 0˚, (b) 30˚, (c) 45˚,(d) 60˚, (e) 90˚.

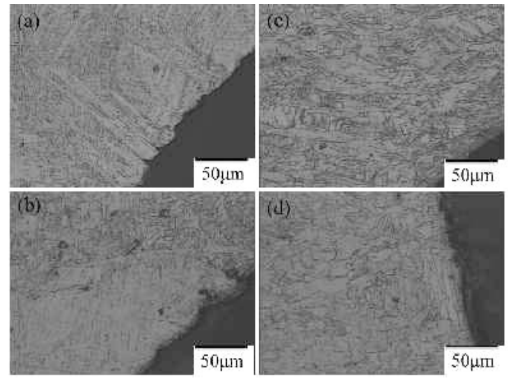

Fig.7 Deformation microstructures of EX-2 with different tilting angle:(a) 0˚, (b) 30˚, (c) 45˚,(d) 60˚.

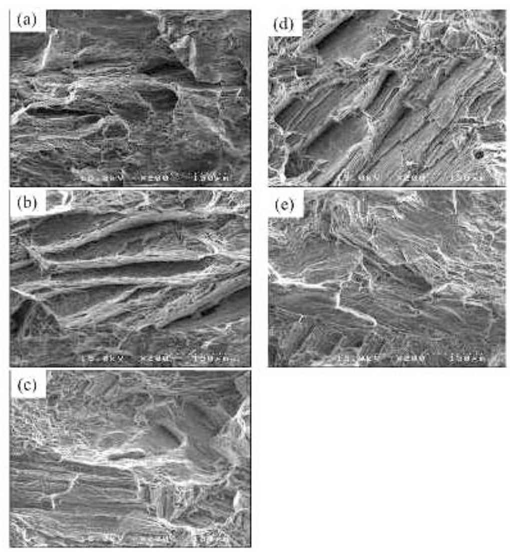

Fig.8 The fracture surface of EX-1 with different tilting angle :(a) 0˚, (b) 30˚, (c) 45˚,(d) 60˚, (e) 90˚.

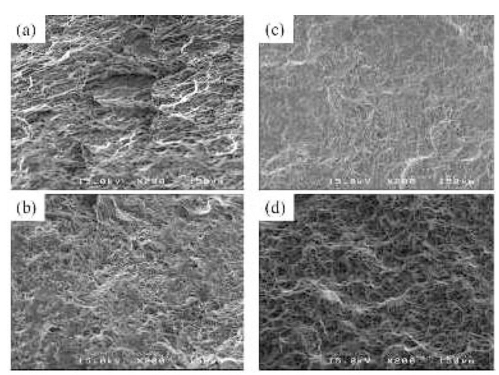

Fig.9 The fracture surface of EX-2 with different tilting angle :(a) 0˚, (b) 30˚, (c) 45˚,(d) 60˚.

4. Conclusion

The effects of the grain size and the tilting angle on the microstructure and tensile deformation behavior of the AZ31 magnesium alloy can be summarized as follows:

- The tensile stress of EX-1 with tensile direction parallel with TD (tilting angle 0˚, EX-1- 0˚) is remarkable lower than of EX-2, and the values of EX-1 and EX-2 become similar with the tilting angle 30˚, 45˚and 60˚.
- The fine grain is characterized anisotropic condition for elongation of extruded AZ31, but no remarkable changes to the elongation of coarse grain with tilting angles 30˚ 、45˚and 60˚.
- The fracture surface of EX-2 have exhibit few plate-like structure to the brittle fracture with tilting angles 30˚、45˚and 60˚, and the microstructure various parts shows ductile fracture on dimple structures.
- This coarse grains structure of extruded AZ31 may in fact have low yield strength of the EX-1-0˚ by some as yet unknown mechanism.

Acknowledgements

This paper has been supported by the Chinese National Science Council (contract: No. NSC 101-2221-E-006 -116 -), for which the authors are grateful.

References

[1] H. W. Lee, T. S. Lui and L. H. Chen,"Studies on the improvement of tensile ductility of hot-extrusion AZ31 alloy by subsequent friction stir process",J. *Alloy. Compd.*, 475 (2009) 139-144.

[2] J. Koike, Y. Sato and D. Ando, "Origin of the Anomalous {10-12} Twinning during Tensile Deformation of Mg Alloy Sheet" *Mater. Trans.*, 49 (2008) 2792-2800.

[3] Z. Keshavarz and M. R. Barnett, "EBSD analysis of deformation modes in Mg–3Al–1Zn", *Scr. Mater.* 55 (2006) 915-918.

[4] M. H. Yoo"Slip, Twinning, and Fracture in Hexagonal Close-Packed Metals", *Metall. Trans. A*, 12 (1981) 409-418.

[5] R. W. Armstrong, "Theory of the Tensile Ductile-Brittle Behavior of Polycrystalline H.C.P. Materials, with Application to Beryllium", *Acta Metall.*, 16 (1968) 347-355.

[6] H. Li, E. Hsu, J. Szpunar, R. Verma and J. T. Carter, "Determination of Active Slip/Twinning Modes in AZ31 Mg Alloy near Room Temperature", *J. Mater. Eng. Perform.*, 16 (2007), 321-326.

[7] S. Kleiner and P. J. Uggowitzer, "Mechanical Anisotropy of Extruded Mg-6%Al-1%Zn Alloy", *Mater. Sci. Eng. A*, 379 (2004), 258-263.