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Microstructure and mechanical properties of AZ31-0.5%Si alloy processed by ECAP

WANG Qu-dong(王渠东), CHEN Yong-jun(陈勇军), ZHANG Lu-jun(张陆军), LIN Jin-bao(林金宝), ZHAI Chun-quan(翟春泉)

National Engineering Research Center for Light Alloy Net Forming, School of Materials Science and Engineering, Shanghai Jiao Tong University, Shanghai 200030, China

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Abstract: Microstructure and mechanical properties of AZ31-0.5%Si(mass fraction) alloy processed by ECAP were investigated. Results show that Mg_2Si phase formed during solidification can be broken up and be dispersed in matrix by ECAP. With the increase of ECAP passes, Mg_2Si phase in microstructure tends to distribute uniformly. The mean grain size is about 4 μm, and the mean size of Mg_2Si is about 6 μm. The elongation of AZ31-0.5%Si alloy is significantly increased after ECAP and then changes a little with increasing ECAP passes. The ultimate strength of as-extruded AZ31-0.5%Si alloy reaches 348.9 MPa, while its strength decreases after ECAP.

Key words: magnesium alloy; microstructure; mechanical properties; Mg_2Si; ECAP

1 Introduction

Magnesium based alloys are attractive in a wide range of structural application due to their low density, high specific strength and excellent machinability[1−2]. The AZ series Mg alloys appear to be among the most widely application because of low cost and moderate room temperature mechanical properties. However, the limited ductility and poor heat resistance have seriously limited their wider application. It was found that the strength and heat resistance can be improved by adding Si to form hard phase Mg_2Si in its microstructure[3−5]. On the other hand, Mg_2Si is very suitable to be used as reinforcement of metal matrix composites for its excellent prosperities such as low density, high melting point, high hardness, low heat expanding coefficient and suitable elastic modulus[6−8]. The Chinese type Mg_2Si particles in AS series Mg alloys produced by casting are usually coarse and brittle, which will impair the ductility. Although numerous efforts to refine the Chinese script Mg_2Si particles by addition element have been reported[3, 9], the Mg_2Si particles refined by equal channel angular pressing (ECAP) has few reported. Therefore, it is necessary to investigate the microstructure and mechanical properties of AZ31-0.5%Si (mass fraction) alloy processed by ECAP.

2 Experimental

The chemical compositions of studied alloys are listed in Table 1. The actual chemical composition of the alloys was determined by spectral analysis apparatus. The ingots were extruded at 573 K with extrusion ratio of 7. The ECAP specimen was cut to 10 mm×10 mm×75 mm. ECAP was carried out on the as-extrusion material through a die made of H13 steel with an internal angle of 90° between the vertical and horizontal channels. The graphite was used as a lubricant. ECAP processing was carried out at 573 K with constant extruding speed of 25 mm/min. All extrusion were conducted by rotating each sample 90° about a longitudinal axis in the same direction between consecutive passes, designated as route Bc. Repetitive extrusions of the same sample were performed up to 1, 2, 3 and 5 passes with equivalent strains of 1.15, 2.3, 3.45 and 5.75. Longitudinal sections were prepared for optical microscopy. The flat tensile specimens with a gauge section of 10 mm×3 mm×1.5

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Corresponding author: WANG Qu-dong; Tel: +86-21-62933139; E-mail: wangqudong@sjtu.edu.cn

Table 1 Chemical composition of alloys (mass fraction, %)

Nominal alloy	Al	Zn	Mn	Si	Mg
AZ31	2.885	0.962	0.345	0.074 5	Bal.
AZ31-0.5%Si	2.629	0.756	0.264	0.487 0	Bal.
AZ31-1%Si	2.388	0.538	0.088	0.854 0	Bal.
AZ31-5%Si	2.827	0.819	0.244	2.206 0	Bal.
AZ31-10%Si	2.764	0.689	0.215	3.652 0	Bal.

mm were cut from the same positions of the materials with electro-discharge machine. The microstructural analysis was carried out using the SEM (Philips-505) equipped with an energy dispersive X-ray spectrometer (EDS). Phases in the AZ31-0.5%Si were analyzed by D/MaxIII A-12KW-Cu type XRD analyzer operated at 40 kV and 120 mA.

3 Results and discussion

3.1 Determination of optimum Si content

Fig.1 shows the change of room temperature tensile properties of AZ31-*x*Si alloys extruded at 573 K with extrusion ratio of 7. It can be seen that both the ultimate strength and yield strength of as-extruded AZ31-0.5%Si alloy reach the maximum value under this experimental condition. When the content of silicon exceeds 1%(mass fraction), both the strength and elongation decrease obviously. Based on the above consideration, the optimal silicon content is determined to be 0.5% and the following research is performed for AZ31-0.5% Si alloy.

3.2 Microstructure

Fig.2 shows that the main intermetallics in AZ31-0.5%Si alloy are Mg_2Si and $Mg_{17}Al_{12}$. Fig.3 shows the microstructures of as-cast, as-extruded, and ECAPed AZ31-0.5%Si alloy. The microstructure of as-cast AZ31-0.5%Si alloy consists of eutectic Mg_2Si with Chinese script type in Mg matrix, which can be confirmed by the binary phase diagram of Mg-Si (shown in Fig.4). The SEM micrographs of as-cast AZ31-0.5%Si alloy clearly present the Chinese script type Mg_2Si in Mg

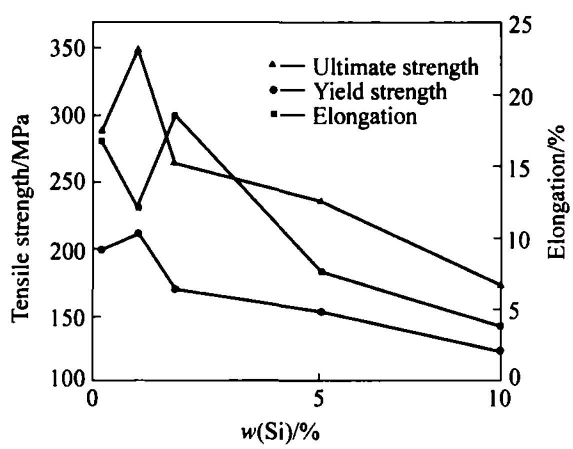

Fig.1 Mechanical properties of as-extruded AZ31-*x*Si alloys at room temperature

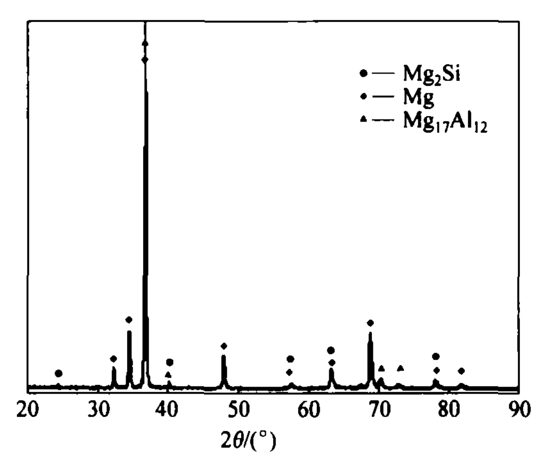

Fig.2 X-ray diffraction pattern of as-cast AZ31-0.5%Si alloy

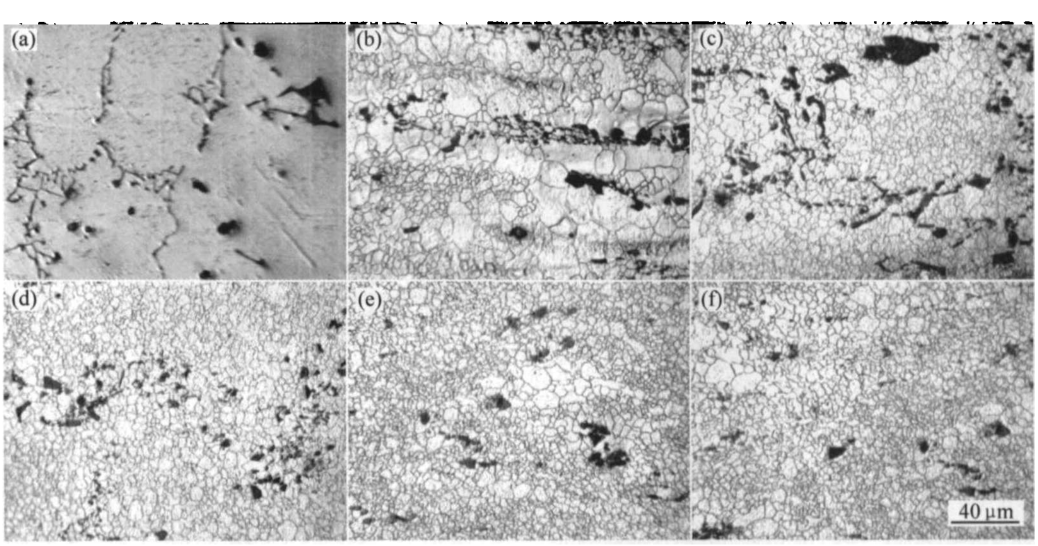

Fig.3 Microstructures of AZ31-0.5% Si alloy: (a) As cast; (b) As-extruded at 573 K; (c) ECAPed after 1 pass; (d) ECAPed after 2 passes; (e) ECAPed after 3 passes; (f) ECAPed after 5 passes

matrix (shown in Fig.5). The composition of Mg_2Si phase in AZ31-0.5% Si alloy is also determined by EDS. After general extrusion at 573 K with extrusion ratio of 7 (shown in Fig.3(b)), the microstructure changes can be observed clearly:

1) The shape of the Mg_2Si phase changes from coarse Chinese script to blocky shape. The Mg_2Si after general extrusion tends to distribute along the extrusion direction.

2) The grain size is in a range from 4 to 30 μm, and the mean grain size is about 20 μm. Figs.3(c)−(f) show that microstructures of AZ31-0.5%Si alloy after ECAP with 1, 2, 3 and 5 passes at 573 K. It can be observed that grain is refined obviously and the Mg_2Si phase can be broken up and be dispersed in matrix by ECAP. With the increase of ECAP passes, Mg_2Si in microstructure tends to distribute uniformly. As can be seen in Fig.3(f), the mean grain size is about 4 μm. The mean size of Mg_2Si is about 6 μm.

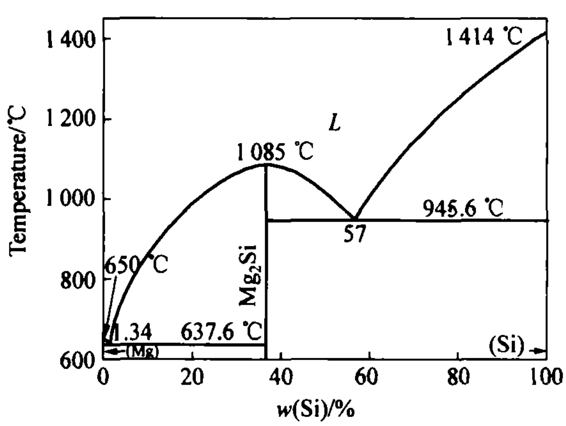

Fig.4 Binary phase diagram of Mg-Si

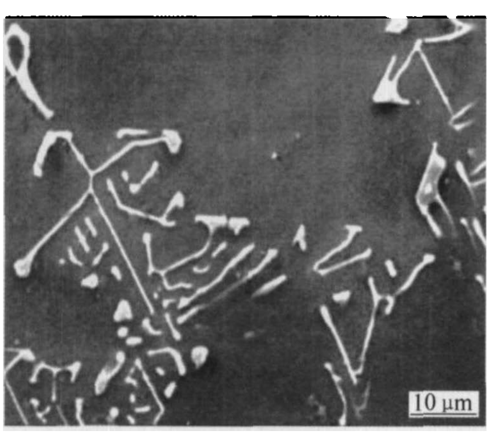

Fig.5 SEM micrograph of Mg_2Si in as cast AZ31-0.5%Si alloy

3.3 Mechanical properties

Fig.6 shows the mechanical properties of AZ31-0.5% Si alloy of the as-extruded alloy (0 pass) and after ECAP with 1, 3 and 5 passes at 573 K. It can be seen that the elongation of AZ31-0.5%Si alloy is significantly increased and the strength decreases a little after ECAP. In particular, the elongation of 1 pass ECAP specimen increases from 12.1% to 20.0% of as-extruded alloy, then it changes a little with the increase of ECAP passes. However, the ultimate strength decreases from 348.9 MPa of as-extruded alloy to 252.5 MPa of 1 pass ECAP specimen, then it changes a little with the increase of ECAP passes. The change of the yield strength is similar to that of ultimate strength. The yield strength will be improved according to Hall-Patch relationship and dispersion strengthened mechanism. The results indicate that strength reduces with the decrease of grain size, which is consistent with the results on AZ61 alloy fabricated by ECAP[10]. It is commonly accepted that the texture softening is dominant over the strengthening due to grain refinement[10].

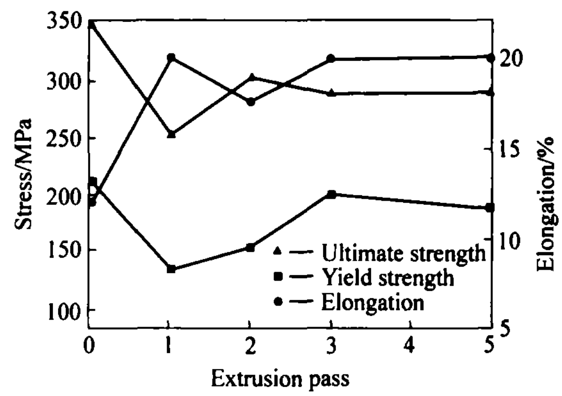

Fig.6 Mechanical properties of AZ31-0.5%Si alloy before and after ECAP

4 Conclusions

1) Mg_2Si phase formed during solidification can be broken up and be dispersed in matrix by ECAP.

2) With the increase of ECAP passes, Mg_2Si in microstructure tends to distribute uniformly. The mean grain size is about 4 μm, and the mean size of Mg_2Si is about 6 μm.

3) Elongation of AZ31-0.5%Si alloy is significantly increased after ECAP and then changes a little with increasing ECAP passes.

4) Ultimate strength of AZ31-0.5%Si alloy reaches 348.9 MPa. The strength decreases after ECAP compared with that of as-extruded alloy.

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