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The deciding role of texture on ductility in a Ce containing Mg alloy

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ABSTRACT

This is the first successful attempt to produce Mg–Ce alloys of different texture through different processing routes while keeping the grain size and grain size distribution same. Tensile data shows that contribution of texture to ductility enhancement is primary and that of grain refinement is secondary. The texture resulting from multi-axial forging of extruded billets followed by annealing exhibits the highest ductility (~40%) at room temperature.

1. Introduction

Magnesium alloys are potentially highly sought after light weight engineering materials in automotive industry to increase the fuel efficiency. However, these alloys have limited applications because of their poor ductility at lower temperatures [1–3] and strong anisotropic behavior [4]. The poor ductility is attributed to insufficient number of slip systems at lower temperatures. In Mg and Mg alloys, basal slip is readily activated because of its low CRSS value [5]. The other easy deformation system that could be activated is tensile twinning. However, for homogeneous deformation without crack formation, generally five independent deformation components are required, which implies that the activation of non-basal slip in addition to twinning is mandatory. The activity of non-basal slip system can be enhanced at lower temperature by alloying additions or by refining the grain size. The addition of Ce to Mg produces homogeneous deformation, enhancing tensile ductility at room temperature without affecting the c/a ratio [6–8] and also increases the corrosion resistance of the material [9,10]. The weakening of basal texture on rolling and extrusion has been reported for Ce containing Mg alloys [11–13]. It is further reported that texture plays an important role in imparting ductility in magnesium alloy [14–16]. A weak basal or a non-basal texture is presumably more favorable for ductility [15,17]. Further, the reduction in grain size is also known to enhance the ductility of magnesium alloys, as grain refinement leads to more grain boundaries, reducing the overall stress concentration at these boundaries which is favorable for the activation of non-basal slip at room temperature [18,19]. Several researchers have observed changes in ductility and strength with different grain size–texture combination obtained through different processing techniques [17,19–23].

However, from the above mentioned reports it is not very clear that out of the two factors, namely, a fine grain size and a weak basal texture which one is more accountable for the increase in ductility in severe plastically deformed materials. In order to carry out an optimal processing, it is important to know the key factor controlling the ductility in magnesium alloys. Hence, it is highly desirable to separate the effect of texture from grain size on ductility of the magnesium alloy under investigation.

2. Experimental procedure

In the present work, different processing routes such as extrusion, rolling and multi-axial forging (MAF) were followed to obtain different textures. The extruded and cast billets of the composition Mg–0.2Ce (wt%) were received from M/s General Motors, Warren, USA. The as-received material was characterized by weak texture and large grain size (above 100 μm) in cast billets and a nearly 20 μm grain size and weak texture for the extruded billets. The extruded and cast billets were subjected to the following processing conditions. All the three differently processed materials were subjected to annealing at different temperatures for an optimized time interval in order to obtain the desired microstructure. The thermo mechanical and thermal treatment schedules are listed in Table 1.

The microstructure and texture of the materials were examined using scanning electron microscope equipped with electron back-scattered diffraction (EBSD) capability. The microstructure of rolled material was examined on the ND–RD plane. For the MAF processed

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Table 1
Grain boundary character distribution and mechanical properties for differently processed materials.

Specimen	Processing schedule		Average grain size (μm)	Grain boundary character distribution		Mechanical properties	
	Thermo-mechanical treatment	Thermal treatment		LAGBS	HAGBs	0.2% proof stress (MPa)	Fracture strain
E+R+A	Rolled at 400 °C, 90% reduction	370 °C, 1 h	(12 ± 11)	0.50	0.50	90 ± 5	0.20 ± 0.02
E+M+A	MAF at 350 °C, 2 cycles	400 °C, 1 h	(18 ± 9)	0.36	0.64	64 ± 3	0.38 ± 0.03
C+M+A	MAF (350 °C→300 °C (2 cycles)	330 °C, 5 min	(13 ± 10)	0.21	0.79	63 ± 2	0.19 ± 0.02

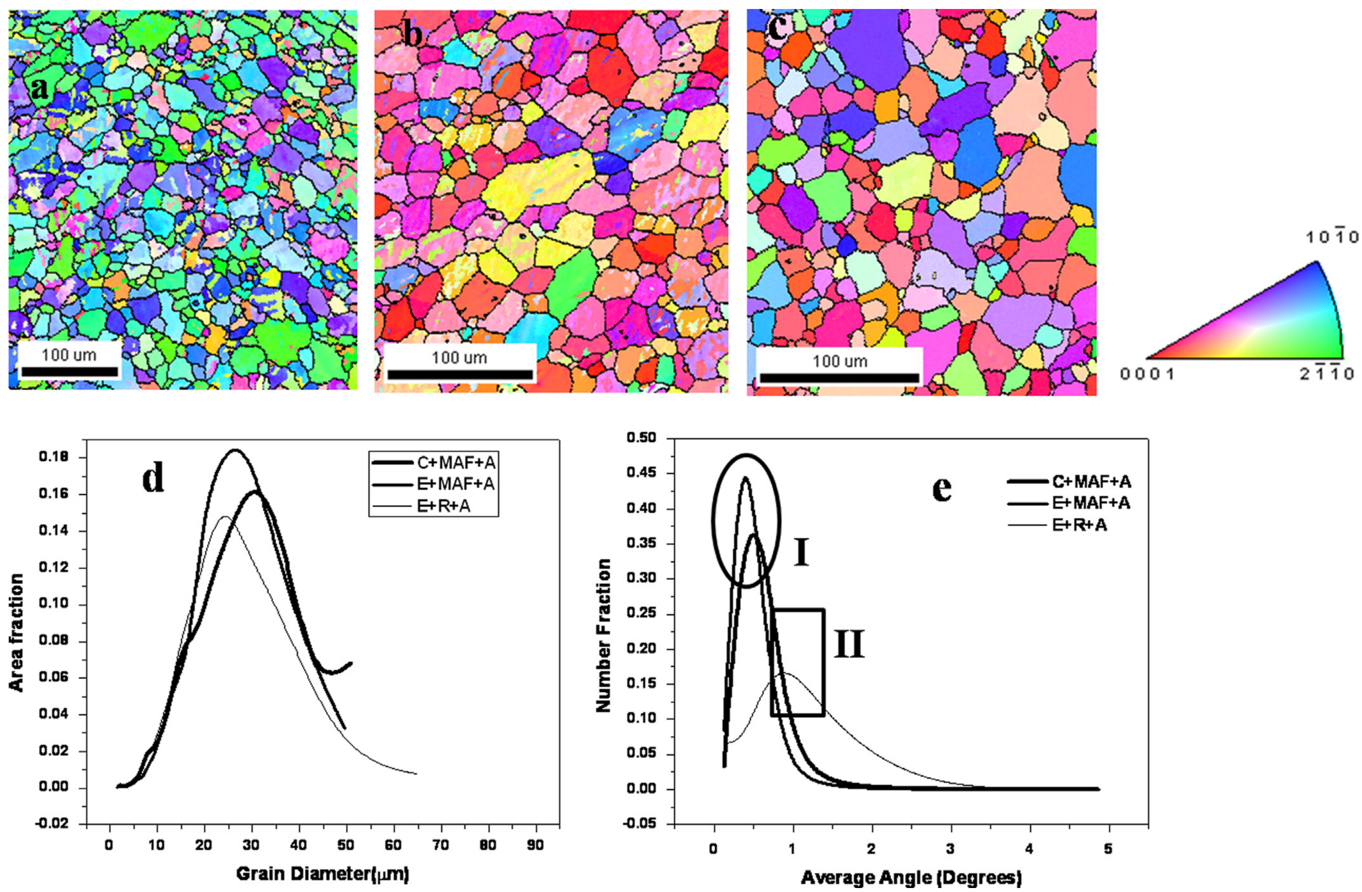

Fig. 1. EBSD generated microstructures presented as IPF maps for the (a) extruded+rolled+annealed, (b) extruded+MAF+annealed, and (c) Cast+MAF+annealed materials, (d) Grain size distribution, (e) Kernel average misorientation distribution for the as-processed samples.

materials, EBSD scans were recorded at the surface which is perpendicular to the compression axis. To analyze the microstructure in detail, kernel average misorientation (KAM) was calculated. It is to be mentioned that KAM is a description of strain in a deformed material. A higher KAM corresponds to higher dislocation density [24]. Tensile tests were carried out at the strain rate $1 \times 10^{-3}\ s^{-1}$. For the rolled samples, the specimens for tensile test were extracted along the rolling direction (RD). For the MAF processed billets, tensile specimens were extracted with the tensile axis along the longer dimension. Minimum three tests were carried out for each condition.

3. Results and discussion

Fig. 1(a–c) represent the EBSD generated microstructures for the samples subjected to processing through different routes. The post deformation annealing was carried out at different temperatures and times for different samples to get similar grain size distribution (Fig. 1d). Fig. 2 displays the (0 0 0 2) and (1 0 $\bar{1}$ 0) pole figures for all the processed samples. From the analysis of grain boundary character distribution (GBCD) (Table 1), it is clear that the rolled+annealed (R+A) material contains high fraction of low angle grain boundaries (LAGBs) in the misorientation range of 2–5°. A small fraction of twins are also apparent in the EBSD micrographs. Fig. 1(e) shows the kernel average misorientation (KAM) distribution for all the samples. It is observed that E+M+A sample has higher number fraction of KAM compared to the others.

Rolling at 400 °C down to 90% reduction followed by annealing (E+R+A), the basal fiber spreads nearly 25° along RD and 10° along TD, respectively. MAF of the extruded billet followed by annealing (in short E+M+A) shows the *c*-axis at an angle of ~22–32° with respect to the compression axis (CD). On the other hand, MAF of the cast billet results in the strongest pole density at an angle 60–75° with respect to the compression axis (CA). The maximum texture intensity for E+R+A and E+M+A is found to be ~7 m.r.d and ~5 m.r.d, respectively. On the other hand, for the C+M+A billets the maximum texture intensity is ~7 m.r.d. The three annealed materials can be considered as the representatives for distinct types of texture, and can be further grouped into two sets based on microstructural features. Set I marked in Fig. 1(e) has