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Double change channel angular pressing of magnesium alloys AZ31

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ABSTRACT

A new extrusion technique, the double change channel angular pressing (DCCAP), is proposed and applied to the technologically important Mg alloys AZ31. The grains of the alloys are found to be refined remarkably by conducting the DCCAP once, which is attributed to dynamic recrystallization induced by heavily accumulated strain and stress. The grain refinement, together with significantly modified textures and tensile fractures, results in a drastic enhancement of mechanical properties of the AZ31 alloys. This DCCAP technique is believed to be able to serve as an effective processing way to tailor Mg alloys for a wide range of engineering applications.

1. Introduction

Wrought magnesium alloys are subject of intensive research for their widespread technological applications, such as in aerospace, automobile, and electronic industries [1–3]. However, they are even inferior in strength to Al alloys, thereby limiting their wide uses as structural components. It has been reported that the strength of Mg alloys can be remarkably improved by means of grain refinement [4]. In addition, recent studies reveal that high ductility can also be obtained for Mg alloys via manipulating structures such as grain refinement and texture control [5,6]. The origin of ductility improvement of Mg alloys can be understood upon the activity of non-basal slip, the grain-boundary sliding, and the recovery at highly strained regions [7]. In view of the critical role of grain refinement, a large number of strategies have attempted [8–11], in which equal channel angular pressing (ECAP) technique has been proven to be rather effective [12]. However, this technique usually requires several passes before grains can be refined [13], thereby resulting in high cost and low efficiency in the practical processing of Mg alloys.

In this work, a new extrusion approach, double change channel angular pressing (DCCAP), is proposed, which can technically avoid dead zone and introduce a severe strain so as to minimize number of passes needed. The DCCAP die not only has the vertical corner as in the ECAP, but also can allow a flexible extrusion because there are two horizontal channels and a smaller diameter than those in the ECAP, which is different from previously adopted methods [14,15]. The DCCAP technique is tested on Mg alloys in order to investigate microstructure change and property shift induced by such a deformation. As an initial step, the generally adopted temperatures, 523 K and 673 K, are used in order to avoid crack formation during deformation. Our results demonstrate that grains of AZ31 alloys are refined significantly, which as a result enhances properties of Mg alloys.

2. Experimental procedure

The Mg alloys AZ31 used have a composition (in mass%) of 3% Al, 1% Zn, 0.3% Mn, and Mg (balance). The DCCAP billets were cut into samples with a size of $\varnothing$ 30 mm $\times$ 60 mm and homogenized at 673 K for 15 h. The DCCAP processing was carried out through a die with an internal angle of 90° between vertical and horizontal channel (Fig. 1). The inner corners are not abruptly sharp, having curvature radii of ~1 mm. The DCCAP die consists of one plunger and two equal sectional dies, which are clamped together so that specimens at each deformation stage can be removed out of the die and thus be investigated independently. The vertical channel is set to 30 mm in diameter, much larger than horizontal channel (10 mm), enabling thereby an intense shearing and extrusion effect. Finite element simulations were performed to study deeply the deformation behaviors of AZ31 alloys using the Deform-3DTM software (Scientific Forming Technologies Corporation). Friction coefficient was set to 0.25, and effective stress and strain were assumed to be elastic or plastic for billet yet rigid for die and plunger. The billet was divided into a mesh with 35,000 $\times$ 7413 nodes

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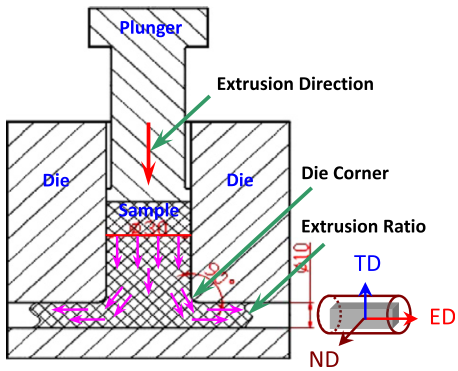

Fig. 1. Schematic of the DCCAP die, showing structure, flow pattern of billet, and extrusion way. The arrows indicate flow process of billet. The ED, ND and TD represent the extrusion, normal and transverse direction, respectively.

and 7026 surface polygons. The billet was pressed through die corner under an extrusion ratio of 4.5 to produce 10 mm rods. With these conditions, the distribution of effective strain and stress was simulated extensively.

Microstructures of samples processed at different stages were observed using the optical microscopy (OM), electron back scatter diffraction (EBSD) mounted on the scanning electron microscope (SEM), and transmission electron microscopy (TEM). Intensive simulations were also performed to provide a quantitative prediction of the distribution of stress and strain. X-ray diffraction (XRD) analyses were conducted in order to characterize the texture evolution. Further, the morphology of tensile fracture was observed by TECSAN-VEGAII SEM, and tensile experiments were conducted under a strain rate of $1.8 \times 10^{-3}\ s^{-1}$ at ambient temperature on specimens with tensile axis parallel to extrusion direction (ED). Micro-hardness of specimens was measured using a digital tester (HXD-1000TM/LCD) under an indenter load of 0.98 N for 15 s.

3. Results and discussion

3.1. Microstructures and textures

Fig. 2 shows representative microstructures of the as-cast and homogenized AZ31 specimens before the DCCAP processing. Clearly, the as-cast alloys are mainly consistent of α-Mg matrix, where there emerge homogeneously distributed fine particles with a volume fraction of over 9% (further XRD analysis recognizes these fine particles as $Mg_{17}Al_{12}$ phase). The volume, however, reduces to less than 2% after homogenization. Moreover, inner grains undergo a significant homogenization as well, as their sizes in the as-cast case span the range from 100 to 240 μm, but from 230 to 300 μm after treatment.

Optical images of the AZ31 alloys are shown in Fig. 3, from which average grain sizes of the alloys processed at 523 K and 673 K are estimated to be about 8 and 35 μm, respectively. Evidently, originally coarse grains are refined remarkably by even a single DCCAP, thus demonstrating its efficiency in refining grain. Another interesting feature is that extrusion temperature is critical to modifying microstructures of AZ31 alloys, namely, the lower temperature, the finer grains, as reported in the ECAE [16]. Furthermore, there exist a large amount of fine grains with size of ~5 μm and some coarse grains of ~40 μm together, suggesting that recrystallization does not take place completely at 523 K. The shearing bands are observed to localize along the ED at 523 K [17,18], which plays an important role in modifying mechanical properties of the AZ31 alloys. Nevertheless, those bands are vanished and grains turn coarse when extruded at 673 K, which is attributable to the complete recrystallization at elevated temperature. Although grains as small as 8 μm can be produced by the forward extrusion at 523 K [19], its extrusion ratio (39:1) is much larger and its original grain size (100 μm) is much smaller. In addition, the ECAP can indeed reduce the grain size of Mg alloys from 24.4 to 8.4 μm at 548 K and from 45.5 to 26.7 μm at 523 K, but

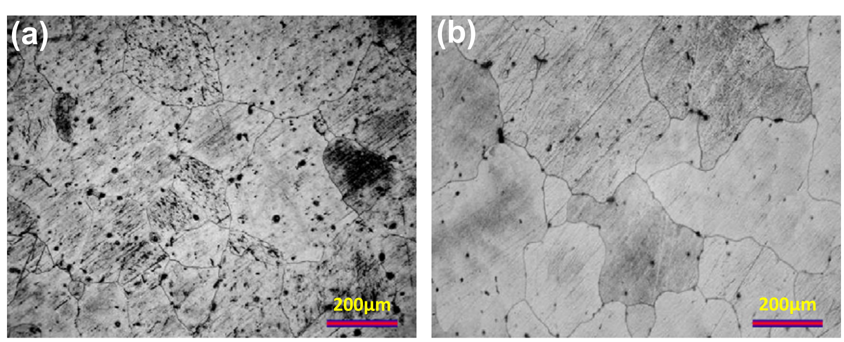

Fig. 2. Optical micrographs of the AZ31 alloys before the DCCAP: (a) as-cast; and (b) homogenized at 673 K.

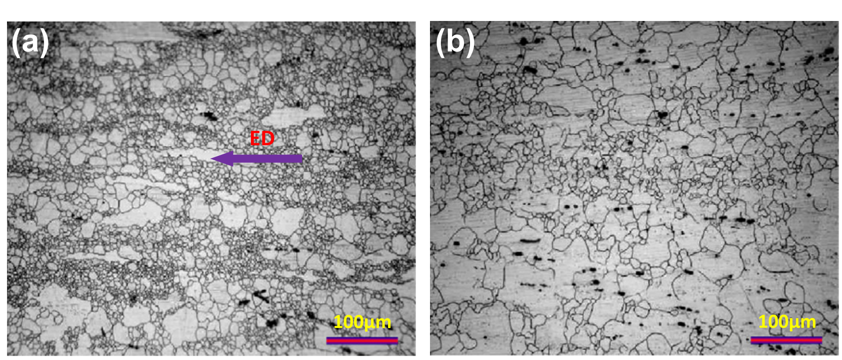

Fig. 3. Optical micrographs of the AZ31 alloys processed by the DCCAP at (a) 523 K and (b) 673 K.