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Microstructure and mechanical behaviour of a $Mg_{94}Zn_2Y_4$ alloy processed by equal channel angular pressing

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ABSTRACT

A $Mg_{94}Zn_2Y_4$ (at%) alloy containing the long-period stacking ordered (LPSO) phase and the $Mg_{24}Y_5$ phase was processed by equal channel angular pressing (ECAP). The ECAP processing develops a bimodal microstructure consisting of large deformed grains (Mg and LPSO) and sub-micron sized dynamically recrystallised (DRXed) grains. The DRXed grain boundaries are decorated with a large numbers of nano-sized $Mg_{24}Y_5$ precipitates. The presence of LPSO lamellae refined the deformed grains by kinking and promoted dynamic recrystallisation during the ECAP process. The ECAP processed alloy was then subjected to the small punch test (SPT). SPT result shows that the ECAP processing increased significantly the strength of the alloy. Under the biaxial tensile stress induced by SPT, the sample started to crack along the ECAP shear direction shortly after the linear elastic region on the load-displacement curve, and the DRXed grains are potential crack sources. These phenomena may be explained by different deformation behaviours of the fibre textured coarse grains and the random oriented DRXed grains, and the distribution of the DRXed grains.

1. Introduction

High strength and ductility are always desirable for structural alloys. This is also true for magnesium based alloys for structural applications. Recently, a Mg–Zn–Y alloy containing a long-period stacking ordered (LPSO) phase has been heavily researched due to its excellent mechanical properties at room temperature and elevated temperatures [1–3]. Much of the work has focused on its structure, strengthening effect, thermal stability and deformation behaviour [4–9]. Thermo-mechanical processes, e.g. hot extrusion, hot rolling and equal channel angular pressing (ECAP), have been carried out on the as-cast alloy to further improve its mechanical performance [10–12]. These thermo-mechanical processes of magnesium alloys often result in the bimodal microstructure, containing coarse grains (including deformed Mg grains and bulk LPSO phases) and fine dynamically recrystallised (DRXed) Mg grains [10,12,13].

Yamasaki et al. [10] studied as-extruded $Mg_{97}Zn_1Y_2$ alloys and suggested that the small, random orientated DRXed grains increased the ductility, while the textured, coarse grains contribute to the strength. Their results [10] were based on the uniaxial tensile/compression tests performed in the direction of extrusion. Since the bimodal structure shows distinct differences along the extrusion and transverse directions of the processed sample, it is interesting and important to study the deformation and cracking behaviour and when other directions are involved in the deformation.

Small punch test (SPT) is a disc bending technique, which was originally designed for testing radiated samples with limited size in the nuclear power industry. It can also be used to analyse the elastic-plastic properties, the ductile fracture toughness J_{IC} and the brittle fracture toughness K_{IC} [14,15]. SPT involves applying a force with a spherical indenter to a thin round disc with the edge clamped by a fixture, as shown in Fig. 1(a). The displacement of the indenter and the force are recorded [16]. As the stress on the disc caused by the spherical indenter is symmetrical along radial directions, it provides a good method to compare the mechanical behaviour and fracture of the bimodal structure in all directions.

In the present study, ECAP is used to modify the as-cast $Mg_{94}Zn_2Y_4$ alloy with the aim of obtaining the bimodal structure and improving the mechanical properties. The mechanical behaviour and fracture of the bimodal structure will be investigated by SPT. The role of coarse grains and DRXed grains in the fracture will be discussed.

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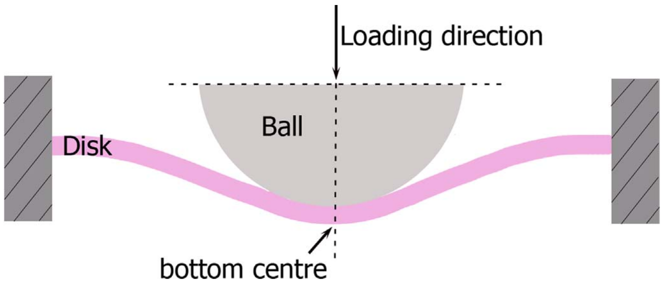

Fig. 1. Schematic drawing of the small punch test.

2. Experimental

$Mg_{94}Zn_2Y_4$ alloys were prepared in an induction furnace under an argon atmosphere using commercially pure magnesium, pure zinc and an Mg-30 wt% Y master alloy. Specimens of 10 mm(width) × 10 mm (height) × 20 mm(length) were cut from the as-cast ingot using a CUT 20 High Precision Wire cut EDM machine. The specimens were ECAP processed for 1, 2 and 3 passes at 300 °C with back pressure. The channel angle Φ and the outer arc angle Ψ of the ECAP die are 90° and 36°, respectively. The specimens were rotated 90° along the same direction between two consecutive passes. The forward pressure and backward pressure during the ECAP were maintained at about 700 MPa and 50 MPa, respectively. After the ECAP process, the three orthogonal planes x, y and z of the sample are defined as perpendicular to the extrusion direction (ED), the transverse direction (TD) and the longitudinal direction (LD) respectively after Ref. [17].

SPT was performed on disc-shaped specimens of Φ8 × 0.5 mm. Thin discs of the ECAPed samples were sectioned parallel to the y plane. The diameters of the loading ball and the lower die for the SPT were 2.4 mm and 4.5 mm respectively. A constant displacement rate of 0.1 mm/min was imposed during the SPTs and the tests were stopped when a 20% load drop was reached. Three tests were carried out under each condition.

The microstructures of the specimens were characterised using optical microscope (OM, ZEISS Axioskop 2), scanning electron microscope (SEM, TESCAN MIRA-3 with an Oxford X-Max SDD detector), and transmission electron microscope (TEM, JEOL 2100 with Oxford Instruments Si(Li) Detector). The deformed

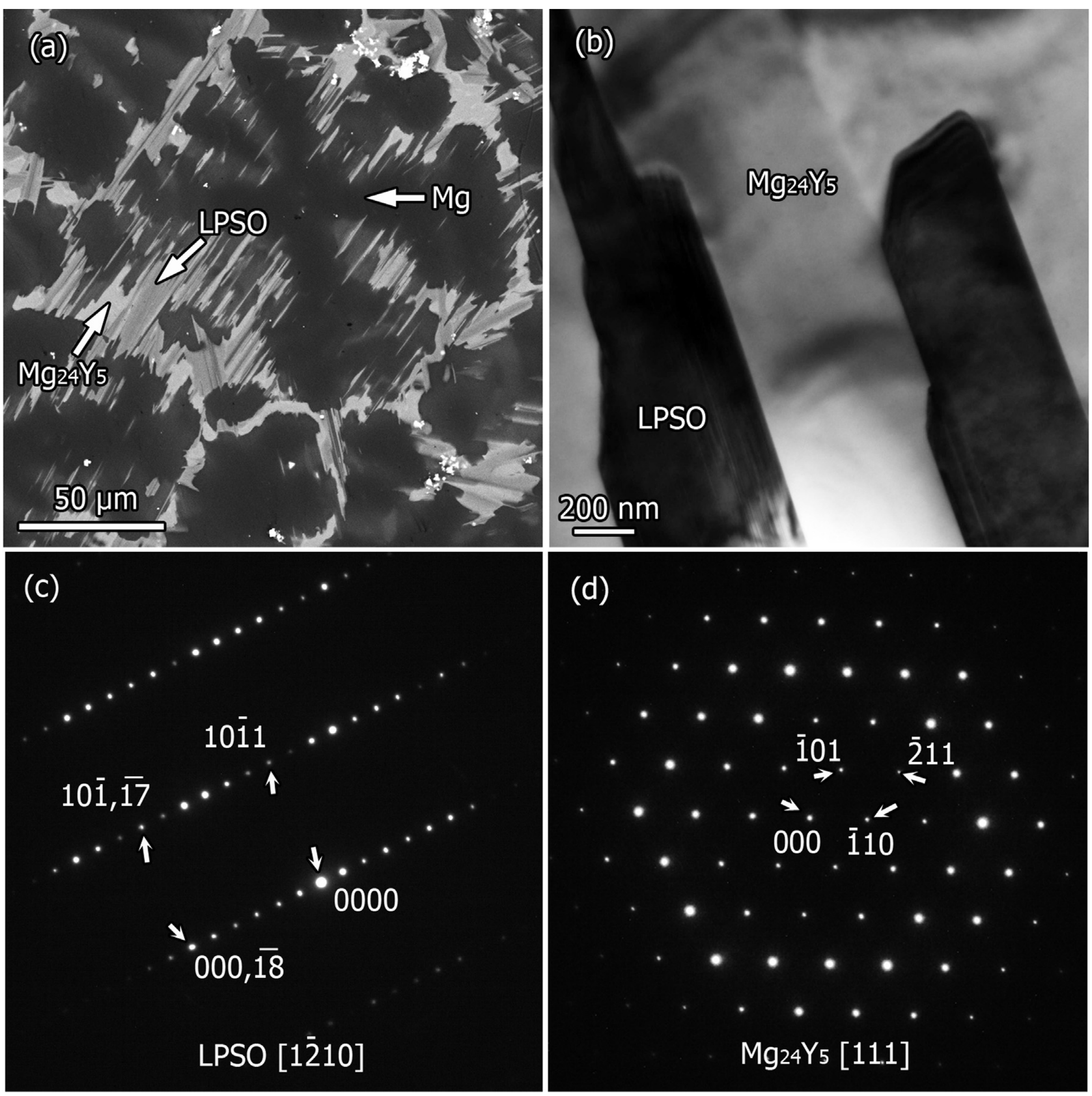

Fig. 2. (a) Backscattered electron image obtained from the as-cast $Mg_{94}Zn_2Y_4$ alloy; (b) TEM bright-field image showing the LPSO and adjacent $Mg_{24}Y_5$; (c) selected area diffraction pattern obtained from the LPSO phase showing it has the 18R type structure; the electron beam direction is parallel to the [1$\bar{2}$10] zone axis; (d) Selected area diffraction pattern obtained from $Mg_{24}Y_5$; the electron beam direction is parallel to the [111] zone axis.