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Room temperature formability of a magnesium AZ31 alloy: Examining the role of texture on the deformation mechanisms

T. Al-Samman *, G. Gottstein

Institut für Metallkunde und Metallphysik, RWTH Aachen, 52056 Aachen, Germany

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Abstract

The deformation behavior, texture and microstructure evolution of six sample types of a commercial magnesium alloy AZ31 with different processing histories were investigated during plane strain compression at room temperature using a channel-die device. Although all the samples were deformed under the same conditions, i.e. temperature and strain rate, the initial state of the samples prior to deformation was responsible for the final texture and microstructure. Stress–strain curves showed a maximum ductility of 28% for the sample with a hot rolling history. EBSD analysis was carried out to give a better insight into the operating deformation mechanisms. Besides the expected $\{10\bar{1}2\}$-tensile twinning, $\{10\bar{1}1\}$-compression twinning and $\{10\bar{1}1\}-\{10\bar{1}2\}$-double twinning were also observed in some specimens and were correlated to microcrack formation, which caused an early shear failure.

Keywords: Slip systems; Twinning; Starting texture; Deformation; Flow behavior; EBSD

1. Introduction

Plastic deformation in Mg and its alloys is strongly affected by (a) the initial orientation of the crystals, i.e. the texture of the material prior to deformation and (b) the deformation conditions, i.e. temperature and strain rate, since the operation of hard slip systems, i.e. non-basal ones requires thermal activation. As a hexagonal close-packed metal magnesium has a limited ductility and poor formability at room temperature due to an insufficient number of operative slip and twinning systems. Besides ductility, Mg alloys also suffer from strong mechanical anisotropy due to the development of pronounced crystallographic textures during mechanical processing. At room temperature there are two dominant deformation mechanisms, basal slip $(0001)\langle 11\bar{2}0\rangle$ which is the easiest and strongly preferred among all slip systems, and mechanical twinning. There are three different $\langle 11\bar{2}0\rangle$ directions in the (0001) plane and thus, there are three basal slip systems, only two of them are independent. Slip on other non-basal systems, like $\{10\bar{1}0\}\langle 11\bar{2}0\rangle$ prismatic slip and $\{10\bar{1}1\}\langle 11\bar{2}0\rangle$ pyramidal slip have in common with basal slip the slip direction in the basal plane, also referred to as $\langle \mathbf{a}\rangle$ slip, but the prismatic and pyramidal slip planes have larger critical resolved shear stresses and therefore are harder to operate at room temperature. Since the above slip systems have a slip direction in the basal plane, they cannot accommodate any deformation out of the basal plane. For an arbitrary deformation slip vectors with a component perpendicular to the basal plane (i.e. parallel to the c-axis) are required, which is referred to as $\langle \mathbf{c}+\mathbf{a}\rangle$ slip, e.g. on the $\{11\bar{2}2\}$ pyramidal plane in the $[11\bar{2}3]$ slip direction [1–3]. $\langle \mathbf{c}+\mathbf{a}\rangle$ slip offers five independent slip systems, i.e. satisfies the Taylor criterion but it has a substantially larger slip vector compared to $\langle \mathbf{a}\rangle$-slip and thus, a markedly higher critical resolved shear stress (CRSS) and requires therefore thermal activation (>225 °C). In addition to basal slip, the presence of mechanical twinning at room temperature could provide the crystals with more independent deformation modes. However, due to the unidirectional nature of twinning and their limited functionality Brown et al. [4] proposed an additional half of an independent deformation mode upgrading the total number of independent slip systems in magnesium at room temperature to 2.5.

Agnew and Duygulu [5] studied the influence of macroscopic parameters on the sheet formability, such as strain hardening rate and strain rate sensitivity by conducting tensile tests at a wide range of temperatures and strain rates. They reported that with increasing temperature ($RT \rightarrow 200$ °C) the strain hardening rate

* Corresponding author. Tel.: +49 241 80 26861; fax: +49 241 80 22301.
E-mail address: al-samman@imm.rwth-aachen.de (T. Al-Samman).

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remained constant ($n = 0.12$), whereas the value of the strain rate sensitivity increased 15 times, from $m = 0.01$ to $m = 0.15$ which represents a reasonable explanation for the significant ductility improvement at 200 °C.

In contrast to cubic materials, particularly fcc systems, hexagonal materials offer a large variety of slip and twinning systems. Their activation depends mainly on the *c*/*a* ratio of the material and also on the deformation geometry and the starting orientation prior to deformation. This study is concerned with the deformation to failure behavior of an AZ31 alloy at room temperature. We use different processing histories of specimens (rolled, extruded, and equal channel angular processed) to examine the role of the initial conditions, i.e. starting texture and microstructure on material formability. This is appropriate for an investigation of formability, since the activation of different slip and twinning modes, particularly in the beginning of deformation, depends strongly on the starting texture and microstructure. Knowledge on the mechanism(s) that cause premature failure, typical of wrought magnesium alloys deformed at room temperature is indispensable for magnesium alloy design. This requires control of texture and microstructure to improve formability at room temperature.

2. Experimental procedure

The material used in the current study was a commercial magnesium alloy AZ31, obtained in three different states of thermo-mechanical processing, each showing a slightly different chemical composition and significantly different texture and microstructure. The conditions of the as received materials were hot rolled, hot extruded, and equal channel angular extruded (ECAE) in four passes, respectively. To cover a wide range of investigations and explore the influence of a large variety of initial orientations on the deformation behavior, six different starting textures were taken into account in this work. The starting textures were obtained by cutting the samples in such a way that the basal plane was essentially parallel to any desired direction for the given channel-die geometry (Fig. 1). The dimensions of the specimens for the plane strain compression (PSC) tests were 14 mm × 10 mm × 6 mm.

For room temperature deformation, plane strain compression was chosen and carried out at a constant strain rate of $10^{-4}\,s^{-1}$ using a channel-die device. Extension occurred only in the longitudinal direction (parallel to RD) since deformation in the transversal direction was suppressed, owing to the geometry of the channel-die device. All tests were conducted to failure and the variation of stress and strain was monitored by a computer equipped with an automated data acquisition system. Machine stiffness was not taken into account. Boron nitride powder was used as a lubricant for minimizing friction between sample and channel-die. After completion of the tests, specimens for optical microscopy were shortly ground with a 4000 grit SiC paper and subsequently mechanically polished with diamond paste down to 3 and 1 μm. Final polishing was performed using a colloidal silica solution. After polishing, specimens were etched in acetic picral to visualize grains and grain boundaries. For EBSD analysis some selected samples were additionally electro-polished in a 5:3 solution of ethanol and H_3PO_4 to achieve best surface quality. The macrotexture was determined in the mid-plane of the failed specimen by measuring incomplete pole figures ($5° \leq \alpha \leq 75°$) in back reflection mode using Co Kα radiation. A set of six pole figures [$\{10\bar{1}0\}$, $\{0002\}$, $\{10\bar{1}1\}$, $\{10\bar{1}2\}$, $\{11\bar{2}0\}$, and $\{10\bar{1}3\}$] was used to calculate the orientation dis-

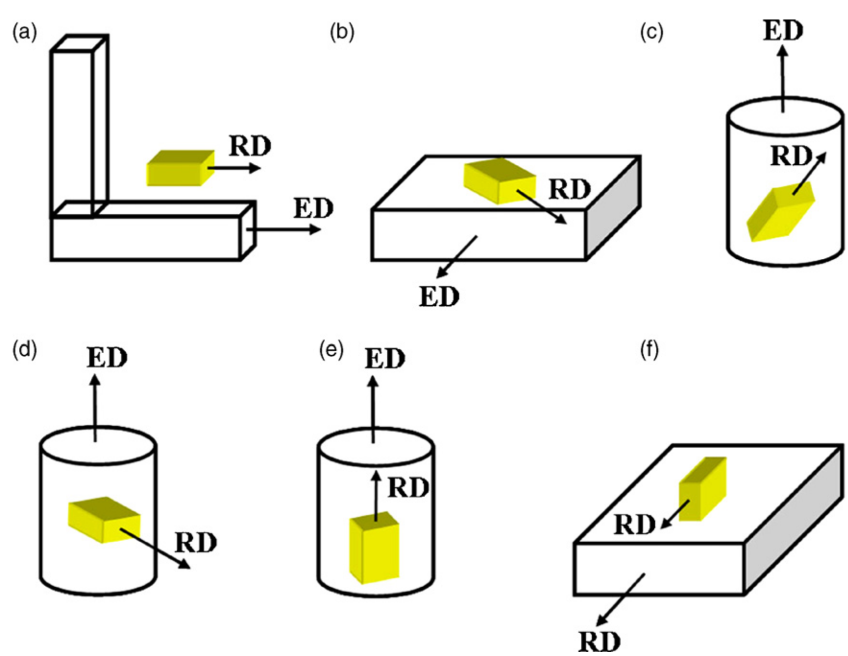

Fig. 1. Orientation of the investigated sample types in the processed material and selection of a new reference system represented by the rolling direction RD of the PSC-samples with respect to the original loading direction (extruded ED or rolled RD) of the as-received material: (a), four passes ECAE; (b) 45° cut from an extruded block; (c) 45° cut from an extruded rod; (d) 90° cut from an extruded rod; (e) 0° cut from an extruded rod; (f) cut from a hot rolled sheet with RD (sample) || RD (original), ND (sample) || TD (original).