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Influence of Crystallographic Texture on the High Cycle Fatigue of Extruded AZ31 Magnesium Alloy

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Abstract. The influence of crystallographic texture on high cycle fatigue behaviour has been studied using an extruded rectangular profile of the AZ31 (Mg-Al-3wt%-Zn-wt1%) alloy. The fatigue samples, cut at 0, 45 and 90° to the extrusion direction correspond to different initial textures. Besides high cycle fatigue tests, quasi-static tensile and compression tests were performed to assess the tension-compression asymmetries as a function of the initial texture. The micro-mechanisms of fatigue crack initiation were investigated using scanning electron microscopy and electron backscatter diffraction. Differences in the mechanical properties and the endurance limit for the different sample directions are related to the initial texture and, subsequently, the easiness or difficulty of slip/twinning.

Introduction

Magnesium alloys, as the lightest structural metallic material with high specific strength, are attractive for light weight construction. However, strong directional anisotropy of the mechanical properties and the tension-compression asymmetry hinder industrial applications of magnesium alloys. The anisotropic behaviour is mainly caused by the strong crystallographic texture which is developed during thermo-mechanical treatments, such as extrusion. Controlling the texture during thermo-mechanical treatments may help to overcome this problem. For example, a weak texture results in a high ductility and an increase in the work hardening capability [1]. An understanding of the relationship between the mechanical properties under (quasi-) static and dynamic loading and the initial texture is still lacking. In the present study, the influence of the initial texture on the mechanical and fatigue properties has been investigated. Mechanical response, fatigue life and fatigue crack initiation mechanisms are analysed and related to the initial textures.

Experimental

A DC-cast billet of AZ31 (Mg-3wt%Al-1wt%Zn) alloy was heat treated for 15 hours at 350 °C. After the heat treatment, rectangular profiles of 12 x 93 mm were extruded by direct extrusion at 250 °C with a constant ram speed of 10 mm/s and an extrusion ratio of 1:10.

The specimens used for tensile, compression as well as fatigue tests were machined with different sample axes with respect to the extrusion direction (0, 45, 90°). Tensile specimens with a gauge length of 30 mm and a diameter of 6 mm and compression specimens with a gauge length of 17 mm and a diameter of 11 mm were used. The quasi-static loading tests under tension and compression were carried out using a universal testing machine (Zwick Z050) at room temperature with an initial strain rate of 10^{-3} s^{-1}. Fatigue tests were performed on electrolytically polished specimens (diameter 7 mm and gauge length 40 mm) using a rotating bending machine (Zwick UBM 200, at 70 Hz and room temperature in air.

To analyse the microstructure by optical microscopy, standard metallographic sample preparation techniques were employed, including the use of an etchant based upon picric acid [2]. EBSD measurements on the fatigued samples after fracture were conducted to measure the local texture at selected points and to investigate the crack initiation with respect to the grain orientation. The EBSD measurements were made near to the microcracks found at the specimen surface. The global texture was determined using an X-ray diffractometer (Panalytical) with CuK$_\alpha$ radiation in the reflection geometry. The (00.2), (10.0), (10.1), (10.2) and (11.0) pole figures were measured and the complete pole figure was calculated.

Results and Discussion

Microstructure and Initial Texture. The optical micrograph of the as-extruded AZ31 illustrated in Fig. 1a shows the microstructure from the perspective of the transverse direction. A significant inhomogeneity is observed in this microstructure, which contains both large grains and small equiaxed grains. Moreover, many unrecrystallized regions can be also observed. The average grain size is about 8 µm. The unrecrystallized grains are very important when deformation mechanisms of wrought magnesium alloys are considered, since they are favourably oriented for deformation by twinning [3].

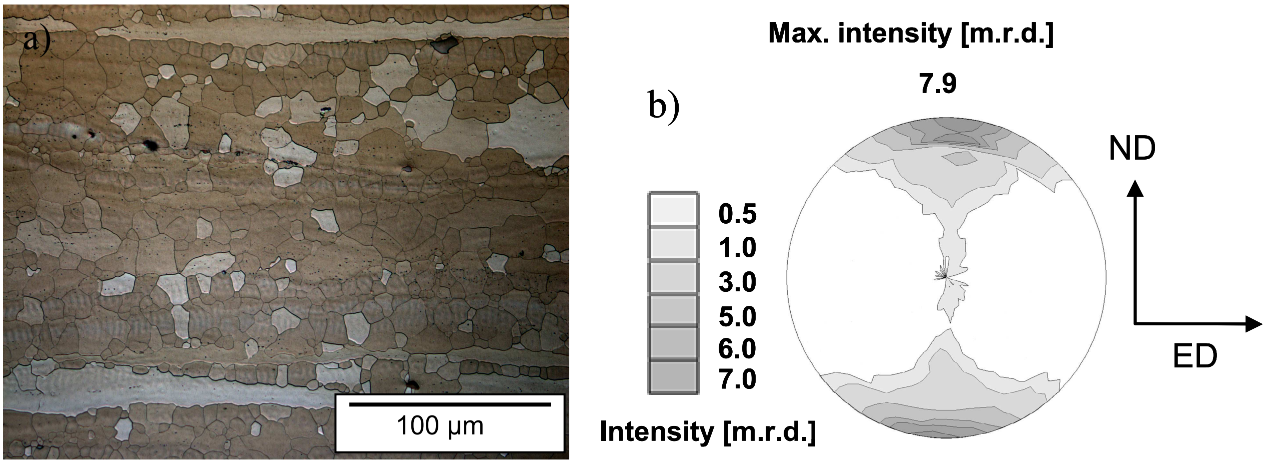

Fig. 1 a) Optical micrograph and b) Recalculated (0002) pole figure of extruded AZ31 alloy transversal to the extrusion direction

In Fig. 1b the recalculated (0002) pole figure shows that a strong basal texture developed during the extrusion, with the majority of grains having their basal planes parallel to the extrusion direction. Moreover, a minor texture component is observed in the centre of the pole figure, which corresponds to grains having their c-axes aligned along the transverse direction (TD).

Mechanical and Fatigue Properties. The results of the tensile and compression tests on the extruded AZ31 samples with different sample axes are summarized in Table 1.

In all directions a significant mechanical yield asymmetry, i.e. difference between tensile and compressive yield strength, is observed. As the {10-12} twins in Mg alloys generate extension along the crystal c-axis, their activation is strongly influenced by the texture. Because compressive loading in all sample directions leads to easy activation of {10-12} twinning, the plastic strain begins at low stresses. During tensile loading, twinning is suppressed for geometrical reasons and basal slip needs high stresses because of the low Schmid factor, such that a high yield strength results [3, 4]. It should be pointed out that the minor texture component of the basal poles aligned in the TD is favourable for {10-12} twinning under tensile loading, Fig. 1b. For this reason, the lowest tensile yield strength is found in the 90° sample.

Table 1. Mechanical properties of extruded AZ31 with different sample axes.

Sample Axis	Tensile Yield Strength (MPa)	Ultimate Tensile strength (MPa)	Elongation (%)	Compressive Yield Strength (MPa)	Ultimate Compressive strength (MPa)	Elongation (%)
AZ31- 0°	167	253	17	98	360	10
AZ31- 45°	154	246	20	91	363	14
AZ31- 90°	155	228	8	94	369	11

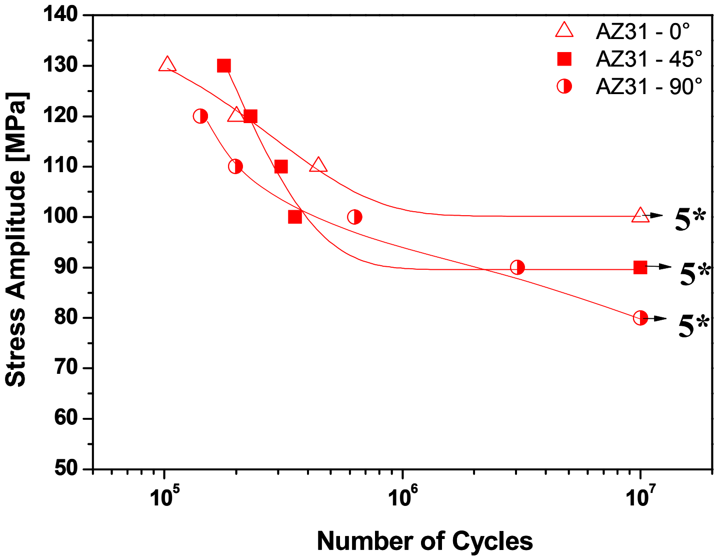

Fig. 2. S-N curves in the different loading directions, 0, 45 and 90° to the extrusion direction; the arrows indicate run-out conditions and the asterisks numbers of run-out samples.

The S-N diagram for the AZ31 extruded profiles with different loading axes is shown in Fig. 2. The endurance at 10^7 cycles is 100 MPa in the extrusion direction (0° samples) and the fatigue ratio calculated using the tensile yield strength is 0.60. The samples loaded in the transverse direction (90°) show the lowest value of the endurance limit of 80MPa, while the 45° samples have an endurance limit of 90 MPa at 10^7 cycles. The fatigue ratios are 0.52 for the 90° samples and 0.58 for the 45° samples. Since the stress ratio for rotating bending is R= -1, the samples underwent a half cycle under tension and half cycle under compression. As explained above, the texture of the 0° sample is not favourable for {10-12} twinning under tensile loading conditions. The suppression of twinning activity leads to restrained plastic deformation in the half cycle under tensile loading of the 0° sample. This restraint of plastic deformation leads finally to a higher endurance limit. In the transverse direction, i.e. the 90° samples, {10-12} twinning is favoured which leads to plastic deformation of the sample during the tensile half cycle. As tensile twinning is the main crack initiation factor in the AZ31 alloy [5], this sample orientation has the lowest fatigue life in comparison with the other sample directions due to the easiness of tensile twinning induced by the texture.

EBSD analysis confirms the above hypothesis, Fig. 3. EBSD measurements were made on regions around the microcracks at the surface of fractured specimens and {10-12} twin boundaries are depicted in red. In the 0° sample (extrusion direction) a small amount of {10-12} twin boundaries is observed, whereas the 90° sample shows high twinning activity. Twin boundaries act as the main crack initiator in magnesium alloys, as reported in [5]. These results show that the long fatigue life of the 0° sample and the short fatigue life of the 90° sample are caused by differences in the twinning activity, which is in turn related to the texture.

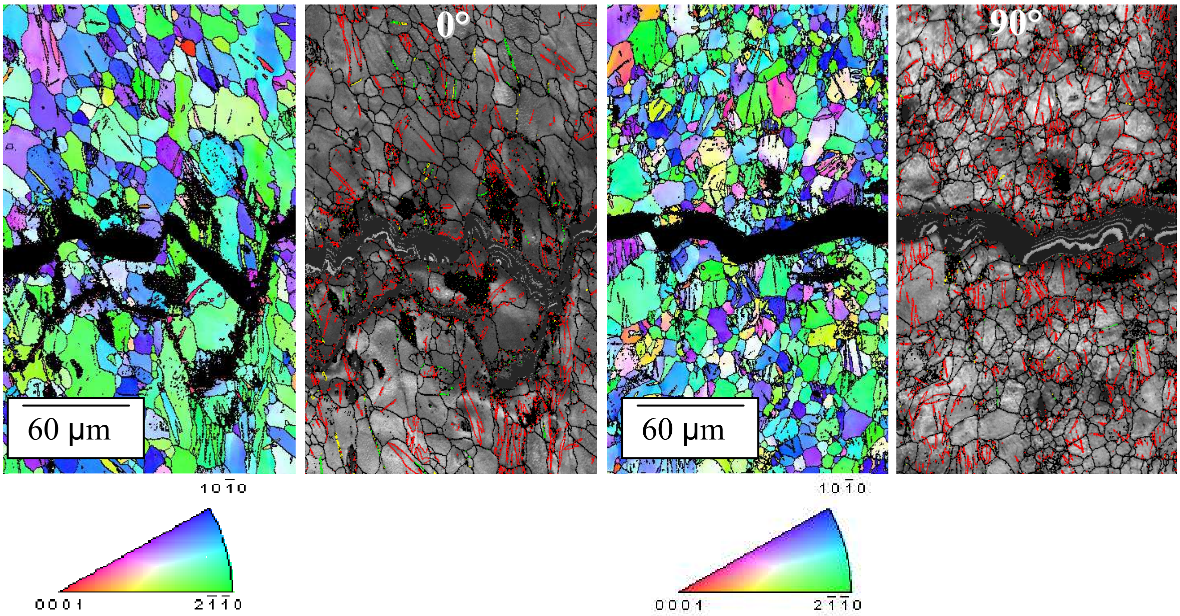

Fig. 3 EBSD orientation maps measured after the fracture of the 0° and 90° samples.

Conclusions

The mechanical properties of AZ31 with different sample axes were investigated. Differences in the texture and mechanical response were correlated with the mechanical and fatigue properties. The AZ31 alloy was characterised by an inhomogeneous structure and strong crystallographic texture, which led to mechanical asymmetry. The best fatigue properties were found in the extrusion direction and the lowest in the transverse direction. This is explained by the fatigue crack initiation mechanism. In this case, the main factor responsible for fatigue crack initiation was the deformation produced by twinning, which is favoured in the transverse direction leading finally to a short fatigue life.

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