ACOUSTIC EMISSION GENERATED DURING TENSILE DEFORMATION OF AN AZ31 MAGNESIUM SHEET

JAN BOHLEN[1]*, FRANTIŠEK CHMELÍK[2], FRANK KAISER[1], DIETMAR LETZIG[1], PAVEL LUKÁČ[2], KARL ULRICH KAINER[1]

Acoustic emission (AE) is observed and analysed during tensile deformation of an AZ31 (Mg-3wt.%Al-1wt.%Zn) magnesium sheet in dependence on the strain rate and the direction of applied stress with respect to the crystallographic texture. The results are explained in terms of dislocation glide and deformation twinning as the main mechanisms controlling plastic deformation and related acoustic emission. Deformation twinning can enhance the material's ductility and increase the related acoustic emission due to dislocation glide by local reorientation of crystal lattice thereby activating fresh slip systems.

Key words: acoustic emission, tensile testing, twinning, magnesium sheet, AZ31

AKUSTICKÁ EMISE PŘI TAHOVÉ DEFORMACI SLITINY AZ31

V práci jsme se zabývali měřením a vyhodnocením akustické emise (AE) při plastické tahové deformaci hořčíkové slitiny AZ31 (Mg-3hm.%Al-1hm.%Zn) v závislosti na rychlosti deformace a směru tahového napětí vzhledem ke krystalografické textuře. Experimentální výsledky jsou vysvětleny současnou činností dislokačního skluzu a deformačního dvojčatění při plastické deformaci. Deformační dvojčatění sekundárně zvyšuje plasticitu materiálu a akustickou emisi tím, že lokálně mění orientaci mříže, takže může docházet v průběhu celého pokusu k aktivaci čerstvých skluzových systémů.

1. Introduction

Magnesium-based alloys have been developed in the last decade as prospective light engineering materials for structural applications. Unfortunately, owing to the hexagonal close packed (hcp) crystallographic structure magnesium alloys show poor strength and formability [1]. Basal slip is known to be the most important mechanism of plastic deformation in Mg. However, there are only three equivalent

[1] GKSS Research Centre Geesthacht, Max Planck Straße, D 21502 Geesthacht, Germany
[2] Department of Metal Physics, Charles University, Ke Karlovu 5, CZ-121 16 Prague 2, Czech Republic
* corresponding author, e-mail: jan.bohlen@gkss.de

basal slip systems in Mg, but the compatibility of deformation in polycrystals requires at least five independent slip systems. Consequently, secondary (prismatic, pyramidal) slip systems must be activated during deformation, which may result in twinning, primarily in $(10\bar{1}2)$ planes. The activation of twinning is dependent on the grain orientation [1], on the testing mode (tension/compression) and on the c/a ratio (1.624 for Mg). The c/a ratio can be influenced by alloying. Thus, numerous parameters, as orientation distribution of grains, grain size, chemical composition can influence mechanical properties of magnesium alloys.

The acoustic emission (AE), which stems from transient elastic waves generated within a material due to sudden localized irreversible structure changes, is caused by dislocation motion and twinning (see e.g. [2]) and, therefore, yields information on the dynamic processes involved in plastic deformation of the Mg alloy. Friesel and Carpenter [3] were probably the first, who investigated carefully AE during the deformation of pure magnesium and the alloy AZ31B. A distinct correlation of the AE activity with sample orientation, purity, strain rate and the mode of testing (tension, compression) was found. In all cases deformation twinning and dislocation glide were found to be the major sources of AE. Therefore AE is an appropriate method to study dynamic processes involved in plastic deformation of magnesium and magnesium alloys.

The objective of this paper is an AE study of the relation between the mechanisms of tensile plastic deformation and microstructure of an AZ31 magnesium sheet as a function of the applied strain rate.

2. Experimental

A commercial sheet of AZ31 (Mg-3wt.%Al-1wt.%Zn) in a warm-rolled condition was used for this study. The granular structure of the alloy has been studied by using an optical microscope. The specimens (210 mm × 20 mm, thickness 6 mm, following DIN 50 125) were deformed in tension at room temperature in a computer controlled testing machine, at various cross-head speeds giving an initial strain rate from 10^{-5} to 10^{-3} s^{-1}. Tensile stress was applied in two different directions, first being parallel to the rolling directions (RD) and second perpendicular to the rolling direction (transversal direction – TD).

The computer controlled DAKEL-XEDO-3 AE system was used to perform monitoring (two-threshold-level detection recommended by an ASTM standard [4]). Full information on the XEDO system may be found in the web [5]. A miniaturized MST8S piezoelectric transducer (diameter 3 mm, almost point AE detection, a flat response in a frequency band from 100 to 600 kHz, sensitivity 55 dB ref. 1 V_{ef}) was attached on the specimen surface with the help of silicon grease and a spring. The total gain was 94 dB. A comprehensive set of AE parameters involving count rates at two threshold levels (simple amplitude discrimination), AE rms voltage, event count, event amplitude and signal waveforms were evaluated. The AE signal sampling rate was 4 MHz, the threshold voltage for the total AE count N_{C1} and for the burst AE count N_{C2} were 730 and 1450 mV, respectively (full scale of the A/D converter was ±2.4 V). The threshold voltage for the AE event start and the AE event end were 1450 and 965 mV, respectively. The dead-time was 1000 μs.

3. Experimental results

In Fig. 1 micrographs of the AZ31 sheet are shown. They show a partly recrystallised equiaxial microstructure with a grain size distribution over a fairly wide range. The average grain size is 58 μm, however, large grains with a diameter up to 250 μm can be found.

The stress-strain curves and corresponding AE count rates taken at the both threshold levels (N_{C1} and N_{C2}) for the samples tested in RD and TD and at different strain rates are depicted in Figs. 2, 3, respectively. The deformation curves are smooth, indicating a substantial strain hardening and show a fairly large elongation to fracture of about 0.2. The yield strength $R_{\rm p}0.2$ is lower for samples that were stressed in RD than for those stressed in TD, other mechanical parameters show no significant dependence on the strain rate and on the direction of the applied stress. These results are summarised in Table 1. The stress-strain curves correspond with the time dependences of the AE count rates (the AE rms voltage vs. time plots have a similar shape and are not shown here). With the exception of the AE peak, where the count rates achieve a maximum measurable value of 3×10^5 s^{-1}, the count rates increase with increasing strain rate. At subsequent stages of deformation, they

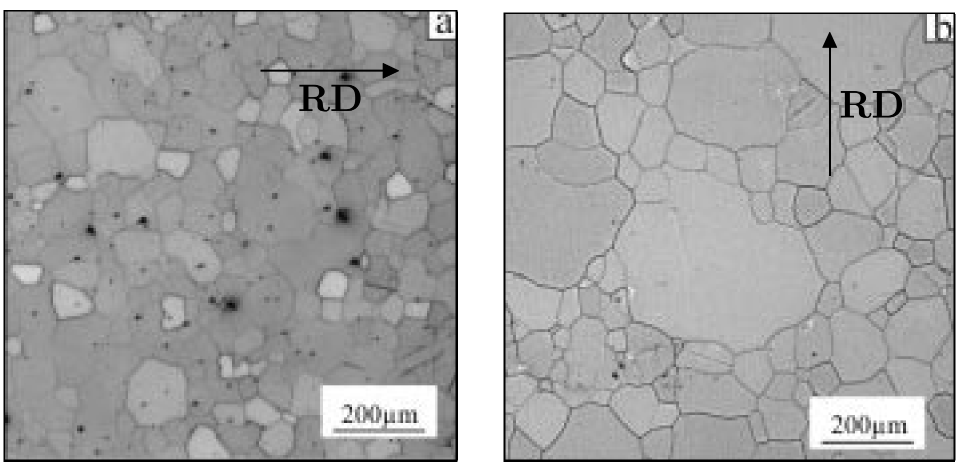


Fig. 1. Typical micrographs of the AZ31 alloy. The rolling direction (RD) is marked by arrows. (a) cross section of the sheet, (b) surface of the sheet.

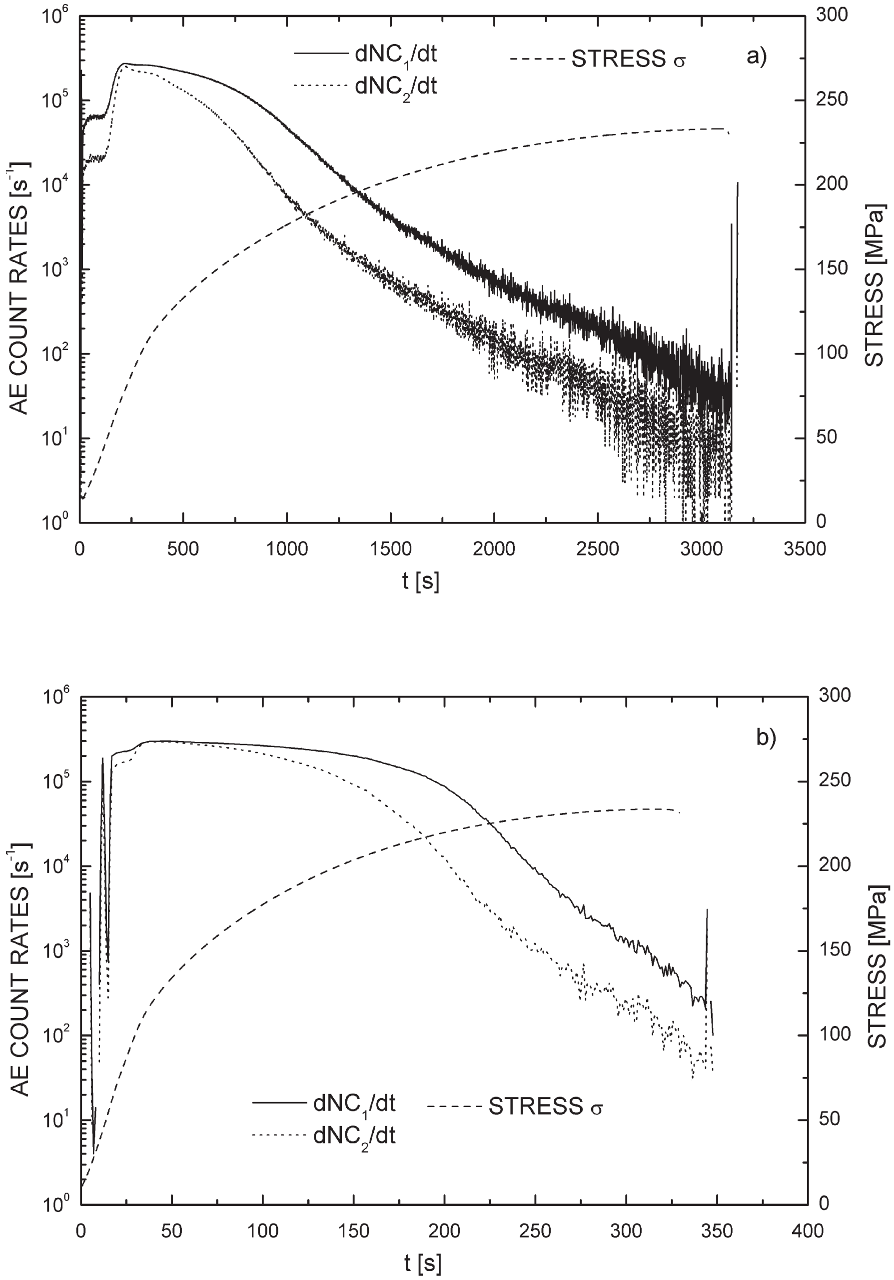
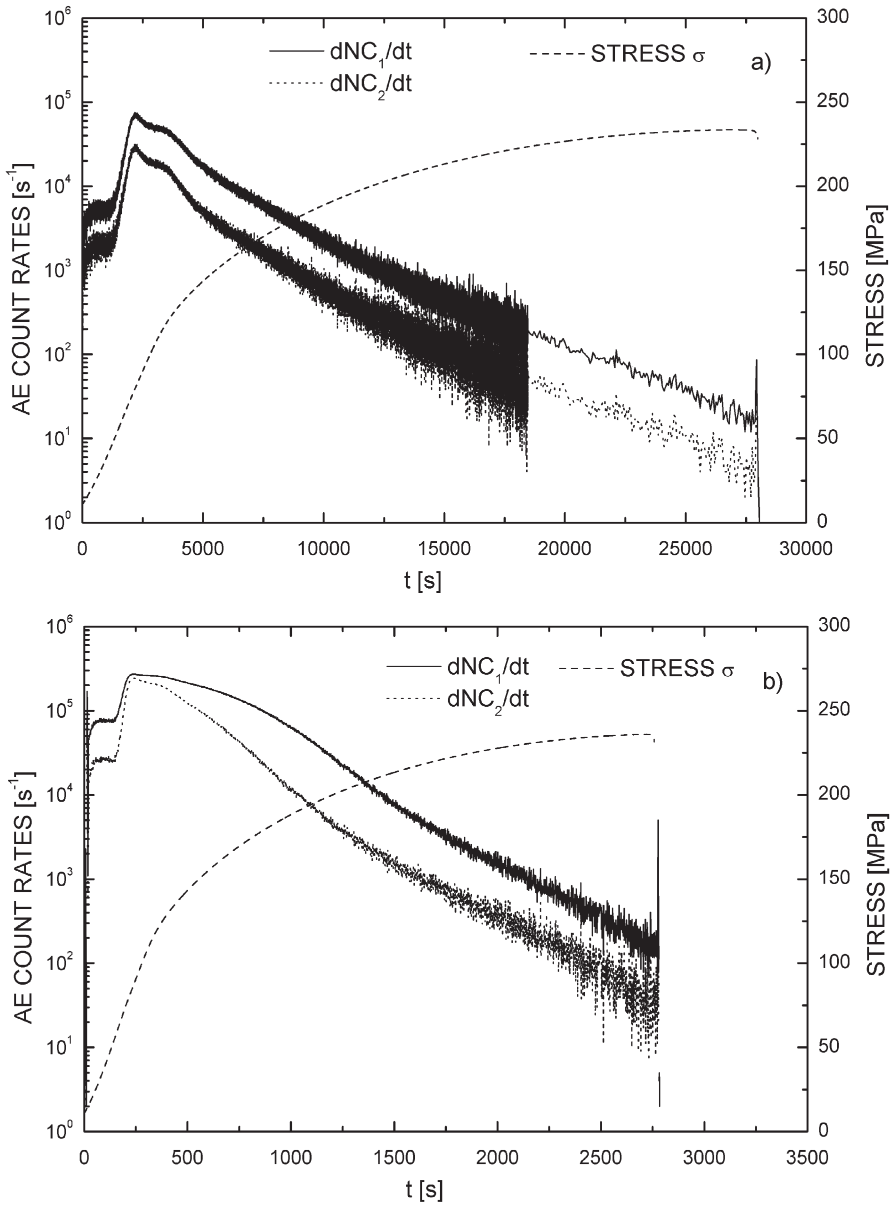


Fig. 2. Stress-strain and acoustic emission count rates curves for the AZ31 alloy stressed in the rolling direction (RD). (a) strain rate 7×10^{-5} s^{-1}, (b) strain rate 7×10^{-4} s^{-1}.



show also a slight dependence on the direction of the applied stress, specifically, the count rates in TD are higher by a factor of 2 than in RD. This corresponds to a slightly higher tensile stress in TD. All dependences exhibit a characteristic maximum related to the macroscopic yield point, which is followed by a decrease in the count rates. However, this decrease is rather slow and a significant AE activity

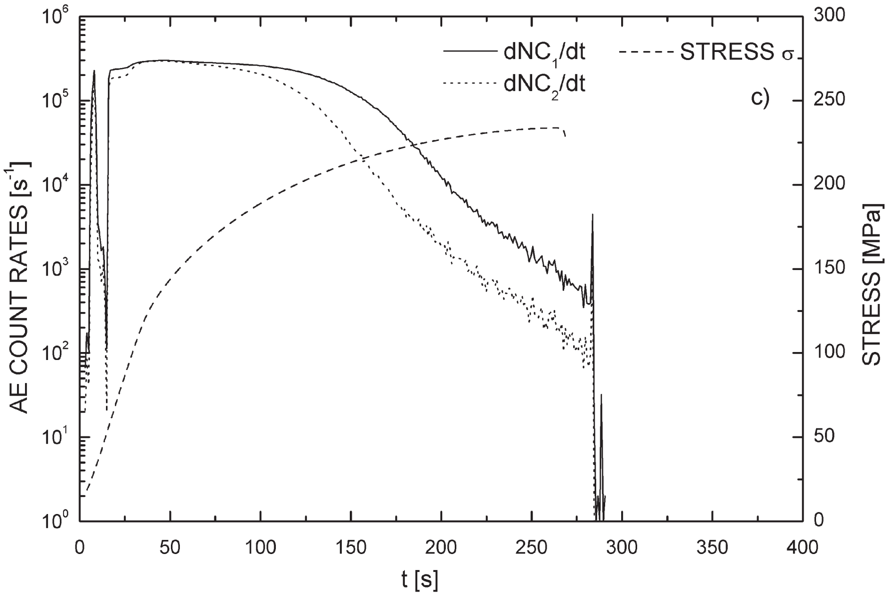


Fig. 3. Stress-strain and acoustic emission count rates curves for the AZ31 alloy stressed in the direction perpendicular to rolling direction (TD). (a) strain rate 7×10^{-6} s^{-1} (from $t = 18500$ s on the counts were taken every 10 s and the count rate was calculated using these averaged values), (b) strain rate 7×10^{-5} s^{-1}, (c) strain rate 7×10^{-4} s^{-1}.

persists until the samples break. Many emissions have a burst character and large amplitude (cf. a substantial AE activity detected on the upper threshold level). This is confirmed by measuring the parameters of the AE events, which show mostly amplitudes larger than 2415 mV (full scale of the A/D converter).

4. Discussion

In the rolled condition, the AZ31 alloy exhibits lower yield strength for the samples stressed in RD than for the samples stressed in TD. Bohlen et al. [6] have shown that the alloy exhibits a non-random texture with a scattering of basal planes being wider in RD than in TD. Thus, the shear stress to activate slip is reached earlier if the stress is applied in RD than in TD.

The plastic behaviour of the AZ31 alloy can easily be correlated with the AE response, as shown in Figs. 2 and 3. The AE peak at the yield point is usually explained by a massive dislocation motion, which has been shown to be an excellent source of AE [2]. The shape of the count rates vs. time dependences is basically similar to that for aluminum and its alloys [2, 7], but for aluminum the count rates decrease much more rapidly with strain than for the AZ31 alloy. The rapid decrease of the AE count rates for Al may be explained by an increasing density of forest dislocations, which reduces both the flight distance and the free length of moving dislocations, consequently, reducing the AE amplitude [2]. This decrease stops at a strain of 0.08 (when the strain hardening coefficient starts to decrease significantly). The different behaviour of the AZ31 alloy can be explained by the presence of twinning as the second deformation mechanism.

Toronchuk [8] and Imaeda et al. [9] found that AE due to twinning is of burst type and variable in amplitude. AE accompanies twin nucleation and growth, but not twin thickening [2]. Chmelík et al. [10] have shown that the AE activity during deformation of pure Zn polycrystals (hcp structure) increased significantly with the grain size which corresponds to larger twins in coarse-grained samples. Friesel and Carpenter [3] found intense burst AE during tensile deformation of an AZ31B tooling plate and interpreted them as a result of intense twinning.

Therefore it is assumed that deformation twinning and dislocation glide play an important role in controlling plastic deformation of the AZ31 alloy. It is noteworthy that deformation twinning can stimulate dislocation glide, because it changes locally the lattice orientation, which can become more favourably oriented for the basal slip. Consequently, the ductility of the alloy can be enhanced and AE can persist throughout the entire test due to gradual activating of fresh slip systems. The transformation of perfect basal dislocations into partial twinning dislocations is the necessary condition for the generation of twinning [11]. Deformation of non-basal slip systems depends on the dislocation core structure and the stacking fault energy [12].

5. Conclusions

Acoustic emission has been observed and analysed during plastic deformation of an AZ31 alloy. The acoustic emission count rates show a well-known correlation to the stress-strain curves revealing a well defined peak close to the macroscopic yield point followed by a subsequent decrease in the acoustic emission activity. The count rates increase with increasing strain rate by a similar factor and also show a slight dependence on the direction of the applied stress (with respect to the rolling direction). The results are explained in terms of dislocation glide and deformation twinning as the main mechanisms controlling plastic deformation and related acoustic emission. Deformation twinning can enhance the material's ductility and acoustic emission due to dislocation glide by local reorientation of crystal lattice thereby activating fresh slip systems.

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