ACOUSTIC EMISSION DUE TO PORTEVIN-LE CHÂTELIER INSTABILITIES IN LOAD RATE CONTROLLED EXPERIMENTS

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Acoustic emission (AE) was observed and analysed during PLC (Portevin-Le Châtelier) plastic instabilities in tests under load rate control. Results of the load rate controlled and former cross-head speed controlled tests are compared. Duration of the AE events increased at the beginning of plastic deformation, however, the events remained separated throughout the tests.

AKUSTICKÁ EMISE PŘI PORTEVINOVĚ-LE CHÂTELIEROVĚ JEVU V REŽIMU KONSTANTNÍHO PŘÍRŮSTKU SÍLY

V práci jsme se zabývali měřením a vyhodnocením akustické emise (AE) při plastických nestabilitách (Portevinově-Le Châtelierově jevu) pozorovaných v tahových deformačních zkouškách s konstantní rychlostí přírůstku síly. Výsledky experimentů jsou porovnány s výsledky získanými při tahových deformačních experimentech s konstantní rychlostí posuvu příčníku na podobném materiálu. Doba trvání událostí AE je vyšší na počátku plastické deformace, události však zůstávají v průběhu celého testu časově separovány.

K e y w o r d s: acoustic emission, Portevin-Le Châtelier effect, load control

1. Introduction

Portevin-Le Châtelier (PLC) plastic instabilities occur in solid solutions as a consequence of the solute atom-dislocation interaction [1, 2]. In an intermediate temperature range, the solute atom diffusion to the dislocations at obstacles increases the waiting time (dynamic strain ageing) [3, 4]. Macroscopically, this leads

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to negative strain rate sensitivity, which is the reason of the PLC effect [5]. Both the solute atom-dislocation and dislocation-dislocation interactions play an important role in the appearance of PLC plastic instabilities [6]. Macroscopically, the PLC effect is characterised by a spatio-temporal localisation of plastic flow, i.e. by repeatedly activating deformation bands in the plastically deformed volume.

The bands show different behaviour (localised, intermittent and propagating) during cross-head speed control, depending on the applied strain rate [7], leading to the appearance of different serration types on the stress-strain curves [8]. During load control, the bands generally show propagating behaviour, which leads to the appearance of regular steps on the stress-strain curve [9]. Hence, in the case of load control the PLC instabilities occur in a relatively simple form. The simplicity of deformation under load control is due to the fact that no load drop corresponds to the appearance of a high strain rate deformation band, i.e. the stress-strain curve is not influenced by the machine compliance [9].

The PLC instabilities can be observed in a region of the strain-strain rate map [3, 10] which is delimited by the critical strain-strain rate points. For instance in tensile tests, the PLC plastic instabilities set in where this critical strain-strain rate curve has been reached.

The acoustic emission (AE) is defined as transient elastic waves generated within the material due to irreversible structure changes and it also responds to collective dislocation motion. Consequently, AE is a justifiable method to study various deformation processes in materials. Generally, during plastic deformation of most metallic materials, the AE count rate changes in a well defined way throughout the test. It shows a peak close to the yield point followed by a decrease toward higher strains. In cross-head speed controlled measurements the AE during the appearance of PLC plastic instabilities can be characterised as follows. The decreasing master-curve of the count rate is superimposed on large AE peaks corresponding to successive appearance of deformation bands (load drops on the stress-strain curve), indicating highly co-operative dislocation motion in the unstable regime [11]. Furthermore, the AE signal waveform is rather continuous in the Lüders regime (usually preceding the PLC effect in annealed samples) and tends to shorter AE events with decreasing event duration as the unstable regime becomes the controlling deformation mechanism [11].

Theoretically, there is no difference between testing under different controlled parameters (load, cross-head speed) during stable deformation, however, in the unstable regime the macroscopic stress-strain curves highly depend on the controlled parameter, indicating also differences in the mesoscopic and microscopic behaviour, which might change also the AE parameters. However, we are not aware of any evidence on AE during PLC instabilities in load-controlled tests.

The objective of this paper is an attempt to apply an advanced and rapid AE monitoring and analysis involving a wide variety of parameters as count rates, event duration, signal waveforms, etc. to monitor the PLC effect in load controlled tensile testing in Al-Mg alloys. The results will be compared with the former results obtained in cross-head speed controlled measurements [11, 12].

2. Experimental

The experiments were carried out on Al-2.7wt.%Mg and Al-4.5wt.%Mg alloys. The average grain size was about 300 μm. Samples of 25 mm gauge length and 6 mm width were cut out of 0.5 mm thick rolled sheets. The samples were subjected to solution heat treatment (470 ℃ for 1 h) and quenched into water.

Tensile tests were carried out at room temperature in an MTS 810 servo-hydraulic testing machine at different but constant loading rates in the 0.2–20 N/s loading rate regime.

The computer controlled DAKEL-XEDO-3 AE system was used to perform monitoring (two-threshold-level detection recommended by an ASTM standard [13]) and sophisticated analysis of AE from the deformed samples. Full information on the XEDO system may be found in web [14]. An LB10A standard AE transducer (almost flat response in a frequency band from 100 to 600 kHz) 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 duration, 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. The threshold voltage for the AE event start and the AE event end were 1450 and 965 mV, respectively. Selected AE signal waveforms were saved through transient recording for a subsequent evaluation. The dead-time was 1000 μs. Detailed description of the investigated parameters can be found elsewhere [11].

3. Results and discussion

In Fig. 1 the stress-strain curves for Al-2.7%Mg and Al-4.5%Mg alloys are shown. The steps in the continuous stress-strain curve are the consequence of PLC plastic instabilities. Each step corresponds to the appearance of a high strain rate PLC band in the sample. This behaviour is essentially similar for all load rates applied. However, the character of the PLC steps is concentration dependent, the steps are more distinct but shorter for the higher Mg concentration. In both curves, the appearance of the steps shows random behaviour as it is observed for non-round cross-section tensile samples [15], as the consequence of the disintegration of the propagating bands into several smaller localised bands [16].

Random appearance of the steps can be explained by the occurrence of localised bands, where the localised bands may only be expected during cross-head

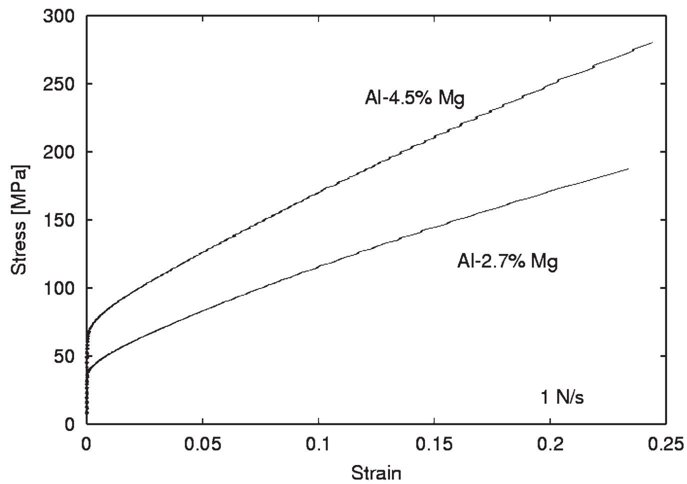


Fig. 1. Stress-strain curves of tensile experiments for Al-2.7%Mg and Al-4.5%Mg alloys at 1 N/s loading rate. The steps indicate the PLC plastic instabilities.

controlled measurements. In load control measurements, the band localisation is very probably caused by the large number of band initialisation sites in the non--round cross-section sample, such as the edges of the sample. For round cross-section samples, similar random PLC band appearance is only observed under special circumstances, where the randomisation of the steps goes back to the initialisation of the first PLC band at very small strain [17].

In Fig. 2 the AE count rate is shown for both alloys. The rate shows three distinct stages throughout the tests. At small load the deformation changes continuously from elastic to plastic deformation (micro-plasticity). The first signs of the plastic deformation are indicated by sporadic AE count rate peaks, which increase in number and size with the load (acoustic yield point). Subsequently, around the conventional yield point ($\varepsilon = 0.002$), a large AE peak is observed. One of the advantages of the load rate controlled experiments is that this small strain region is enlarged.

Following this stage, plastic deformation becomes macroscopic and the AE count rate is high. At the maximum of the AE count rate curve there is a balance between the increasing number of moving dislocations due to mobilising and multiplying, which tends to increase the count rate, and a decrease in the average forest dislocation distance, which tends to decrease the count rate. Both the density of forest dislocations (thereby the internal stress) and the mobile dislocation density can change. In cross-head speed controlled measurements beyond the maximum, the AE count rate decays gradually until the appearance of the PLC plastic instabilities.

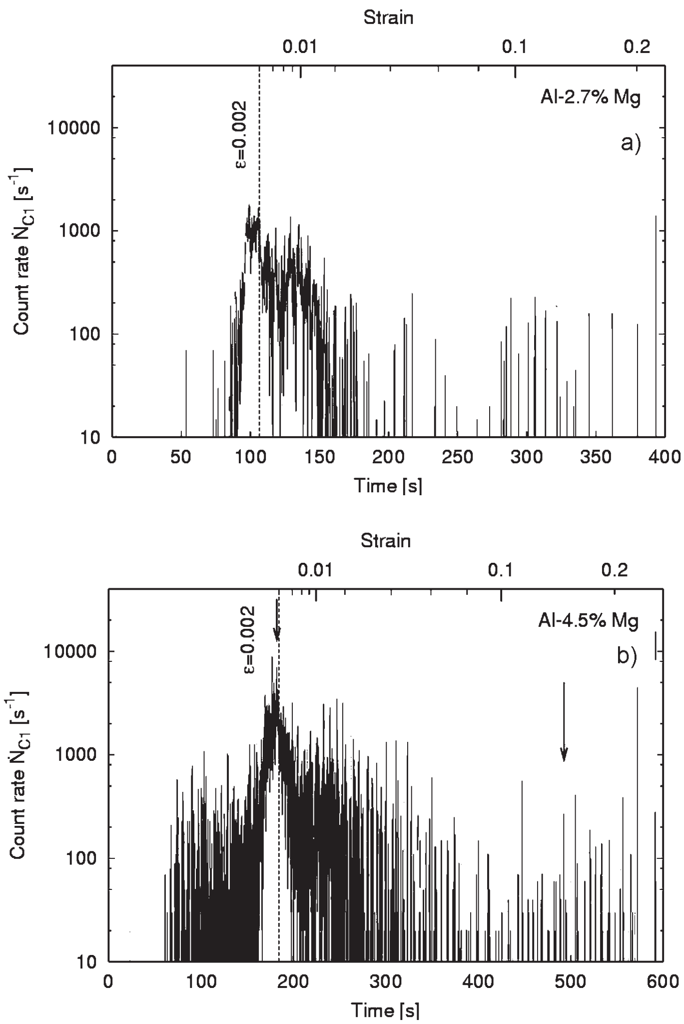


Fig. 2. Acoustic emission count rate curves for Al-2.7%Mg (a) and Al-4.5%Mg (b) alloys at 1 N/s loading rate. The yield strain of $\varepsilon = 0.002$ is indicated by a dashed vertical line.

In the third stage, for longer times and larger strains (Fig. 2), the AE count rate decreases in agreement with earlier results [18, 19], and, additionally, distinct AE count rate peaks appear which are typical signs of the PLC instabilities. Comparing the alloys with the higher and the lower Mg content, in average, the AE count rate peaks are stronger in coincidence with the larger steps for the higher Mg concentration. In Fig. 3, for the alloy with higher Mg concentration, the distinct AE count rate peaks and the corresponding stress strain curve are shown. Each distinct

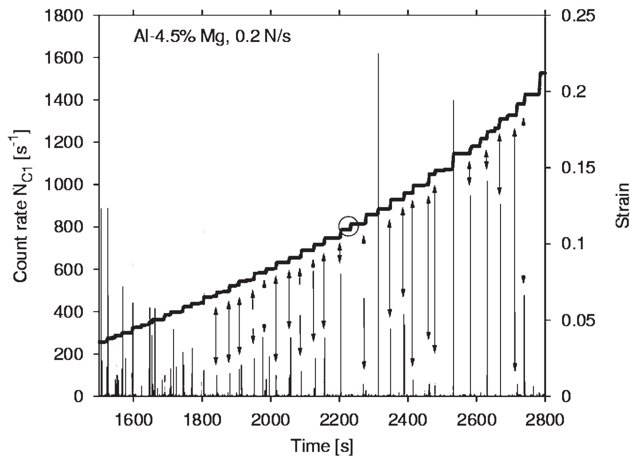
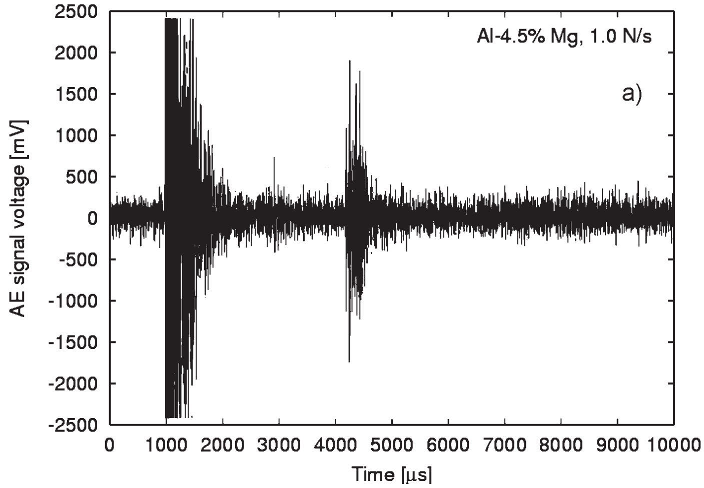


Fig. 3. Acoustic emission count rate and the strain as a function of the loading time. Coincidence between the PLC bands and the peaks of the AE count rates are indicated.

AE peak corresponds to a step in the stress strain curve, i.e. to the activation of a high strain rate PLC band. However, neither the size of the AE count rate peak nor the total AE count per step correlate with the step size. According to earlier laser extensometer investigation [11] in cross-head speed controlled deformation, the creation of larger AE count rate peaks corresponded to the initialisation of PLC band at the heads of the sample. The smaller peaks correspond to the successive appearance of bands along the gauge length of the sample. A similar explanation may therefore be suggested for load controlled deformation.

AE during plastic deformation can be characterised by other parameters than the count rate, such as the event duration and the AE signal waveform. In correlation with the AE count rate, the duration of the AE events change. Under cross-head speed control, AE is continuous in the Lüders regime [11], which leads to a maximum in the AE event duration of several seconds. When the PLC plastic instabilities set in, the event duration decreases and separate events can be observed in the AE signal [11]. In contrast to this, the maximal event duration, which could be determined under the present experimental conditions, was 10^4 μs. Changes of the AE signal with an increase of strain is illustrated for the alloy with higher Mg content in Fig. 4. In Fig. 4a an AE signal typical for the initial deformation stage (yield point vicinity) is shown. Figure 4b shows the AE signal at a later stage during the PLC plastic instabilities. The arrows in Fig. 2 indicate the corresponding AE count rate peaks. The two signals are basically similar, however, the duration of the signal (both parts) at the yield point is significantly longer.



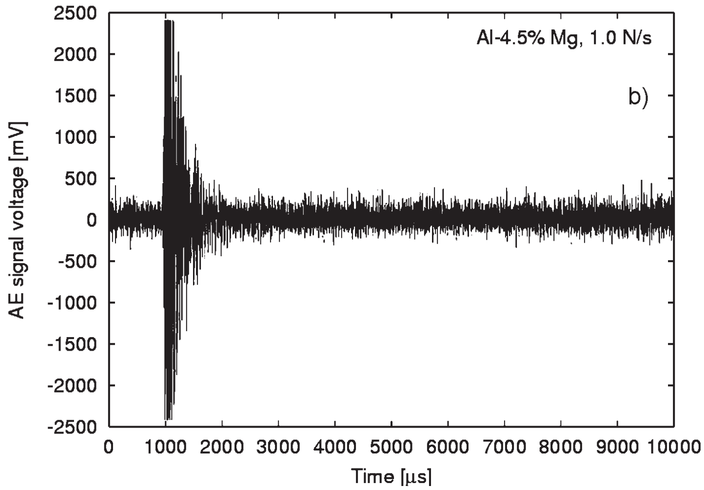


Fig. 4. AE signal waveforms in Al-4.5%Mg of the events at (a) $\varepsilon = 0.0017$ and (b) $\varepsilon = 0.146$ strains. The corresponding events are indicated by arrows in Fig. 2.

Nevertheless, an overlapping of subsequent signals has not been observed at any strain, which is in contrast to the cross-head speed controlled case [11]. This was confirmed by measuring the event duration of each AE event.

Figure 5 shows the duration of the AE events for the alloy with lower Mg content. A maximum in duration can be observed which corresponds to the AE count rate peak. It is noteworthy that (contrary to cross-head speed controlled measure-

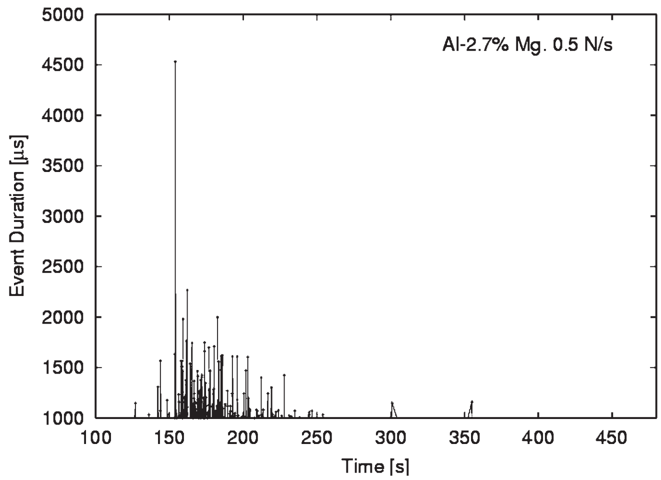


Fig. 5. Event duration as a function of the elapsed time (0.5 N/s loading rate). Separated events can be observed during the entire test.

ments) in load rate controlled measurements separated AE events can be observed during the whole deformation test and the beginning of plastic deformation is indicated only by a slight increase in the AE event duration. This is connected with the low strain rate in the initial regime of load rate controlled experiment. In this connection it is interesting to note that changes in the internal stresses and the mobile dislocation density as a consequence of dynamic strain ageing may be responsible for the post-relaxation effect as observed by Trojanová et al. [20, 21].

4. Conclusions

Acoustic emission was observed and analysed during the PLC plastic instabilities in tests under load rate control. Well-defined AE count rate peaks were observed in coincidence with the appearance of PLC bands. As in cross-head speed controlled tests, the amplitude of the peaks and the size of the strain jumps did not show remarkable correlation. Similarly to the cross-head speed controlled measurements, the duration of the AE event increased at the beginning of plastic deformation, however, the events remained separated throughout the tests. Further AE measurements and analyses are needed for deeper understanding of the PLC dynamics under load control.

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