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THE STUDY OF INFLUENCE OF HIGH PRESSURE TORSION PROCESS ON ACOUSTIC EMISSION ACTIVITY OF COMPRESSED Mg-Li ALLOYS

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In this paper the application of acoustic emission (AE) method is presented to recognize changes of properties of light alloys subjected to large plastic deformations. Measurements were performed on three alloy compositions: Mg10Li, Mg10Li1Al and Mg10Li5Al. Problems related to small dimensions of the samples and low energy of acoustic signals were overcome using the channel-die system to monitor AE effects of compressed samples. As a result of the applied high pressure torsion (HPT) process a strong grain size reduction effect occurred in tested materials. Dimensions of grains diminished considerably resulting in the decrease of the registered AE event rate by almost an order of magnitude.

Keywords: acoustic emission, Mg-Li alloys, channel-die, ultra fine grained (UFG) structures, dislocations, high pressure torsion (HPT).

1. Introduction

Acoustic emission (AE) takes place during rapid release of elastic energy accumulated in the material as a result of acting external incentives or internal phase transitions. External mechanical, chemical or radiation interactions can cause deformational processes during which part of accumulated energy can be emitted in form of elastic waves. Areas of the material, where deformation processes take place, become the source of AE effects. The frequency of acoustic waves is situated between several kilohertz and a few megahertz. They are generated as the effect of initiation and growth of microcracks, local dislocations movement, internal friction, chemical reactions, phase transitions and internal electric discharges in pores or discontinuities [1]. AE method enables sensitive monitoring effects in real time, even in considerable volume of investigated elements. The varying intensity of AE signals enables studying the behavior of investigated metal alloys under mechanical load. Important fact is that evolution of the material microstructure due to applied stress causes the changes of the emitted AE signals. The frequency band of the AE signals generated in such constructional materials as wood, concrete, and metals is considered as approximately from 10 kHz to 2000 kHz. The main theoretical models of AE sources are considered in continuous media [2]:

- *explosion center* (uniform intensity of radiation at each direction x, y, z),
- *shear center* (two pairs of mutually perpendicular forces – i.e. one of expanding and one of compressing type),
- *microcrack* (superposition of both former models).

The analytical description of propagation of AE signal in real object is very complex. The phenomena causing the modification of propagating wave modes are reflections and transformations at the borders of the regions characterized by different acoustic impedance. However, the AE wave propagation for the region situated far from the source in homogenous medium can be described using the Green function of type as below:

$$G(x,t'-t,x) = \frac{1}{4\pi\rho v_p^2}\gamma_i\gamma_j\frac{1}{r}\delta(t'-t-r/v_p) - \frac{1}{4\pi\rho v_s^2}(\gamma_i\gamma_j-\delta_{ij})\frac{1}{r}\delta(t'-t-r/v_s), \tag{1}$$

where v_p – wave velocity of compression mode, v_s – wave velocity of shear mode, γ_i and γ_j – for $i = 1,2,3$ and $j = 1,2,3$ – directional cosines between EA source and AE sensor (i index) and cosines between AE sensor and AE source points (j index), r – source – sensor direction vector, δ_{ij} – Cronecker delta, $\delta(x)$ – Dirac delta function, t' denotes the arrival time to the sensor, t denotes the start of the AE source activity.

During last decade several investigations considering AE effects in metallic materials were carried out in Poland. The majority of these papers was aimed at study mechanisms of AE effects generation in different metals, their compositions, alloys and even single crystals. Acoustic effects and changes in microstructure were analyzed and compared for investigated materials. Research of mechanical properties and their influence on acoustic activity of stressed materials was important aim of part of performed tests. Among them the following can be mentioned:

- AE signal generation during press punching process of different steel compositions [4, 5],
- AE signal generation during phase transition of austenite decomposition into lower bainite [6],
- anisotropy of acoustic emission and Portevin-Le Châtelier phenomena in polycrystalline aluminium alloys subjected to tensile tests [3],
- spectral analysis of acoustic emission signals generated by twinning and shear band formation in silver single crystals subjected to channel die compression tests.

The AE events generated in metals during the processes of formation or evolution of dislocation systems have usually relatively low energy level, when compared to the background noise level. Main sources of AE signals in compressed metallic samples are: creation of dislocations, irregular collective movement of large number of dislocations, their annihilation as well as formation of structures such as deformation twins or shear bands and their propagation. It has been demonstrated that the most essential contribution to the measured acoustic impulses is the collective behavior of the movement of dislocation groups, mainly the acceleration and the annihilation of dislocations occurring especially at the free surface of deformed sample. There exist strong correlations between the measured AE parameters, mainly the rate of AE events and basic dislocation mechanisms of slip as well as strain localization. It is connected with the instability of plastic flow (twinning, Portevin-Le Châtelier effect) and with the formation of primary and secondary groups of the shear bands. It was observed particularly during channel die compression of single crystals at low temperature.

Experience related to AE measurements of metallic samples let the authors to conclude that to obtain the best conditions of propagation of AE signal from the bulk of sample to the sensor, a channel die should be applied as a sample holder during the process of compression. Cubic or cylindrical sample inserted into a channel die and placed on a thick parallelepiped rod used as a waveguide creates good conditions to transmit the AE signals to the AE sensor.

2. Samples preparation and measuring set-up

The research was intended to describe the influence of large plastic deformation on generation of AE signals in compressed alloys Mg10Li, Mg10Li1Al and Mg10Li5Al. The preliminary results of the research were mentioned in [2]. The basic Mg-Li alloys were obtained by the method of induction melting of magnesium of 99.99% purity and lithium of 99.5% purity. The alloys were prepared in Institute of Materials and Machine Mechanics of the Slovak Academy of Sciences. Presented work has been inspired by the fact that strong tendencies for superplastic flow and changes in the activity and intensity of AE in ultra fine grain structures of different alloys, subjected to compression after processing the samples using Equal Channel Angular Pressing device (ECAP), were lastly observed. The idea of the HPT method of torsion under high pressure [2] is that an equivalent strain ε_N is possible to induce in cylindrical sample with R radius of the base and the height l. Thus, after N rotations the equivalent strain $\varepsilon_N = \gamma/1.73$, can be obtained. Samples before HPT tests had the shape of discs of the diameter 10 mm and the thickness 2–4 mm. After large plastic deformation, intended for further compression tests, thickness was in the range 1–2 mm. Samples for mechanical-acoustic testing had small dimensions – smaller than diameter of AE transducer. Additionally, AE signals emitted during compression were characterized by low energy, only a little higher than background noise. It was important to solve problem of registering acoustic emission activity of the samples during compressive force increase. The authors used channel die and thick parallelepiped basement functioning as a waveguide for acoustic signals. Compression tests in a channel die were carried out using the testing machine INSTRON–3382. Velocity of the machine traverse was equal to 0.05 mm/min. Simultaneously with the registration of the external force F, AE signals were recorded applying the instrumentation and the procedure described in paragraph 1. Total amplification of the AE analyzer was 70 dB and sampling frequency was 44.1 kilosamples per second. Every of registered this way AE signals contained 300 MB data of digital samples. The experimental results of AE measurements before and after application of HPT method are presented in Figs. 1–3.

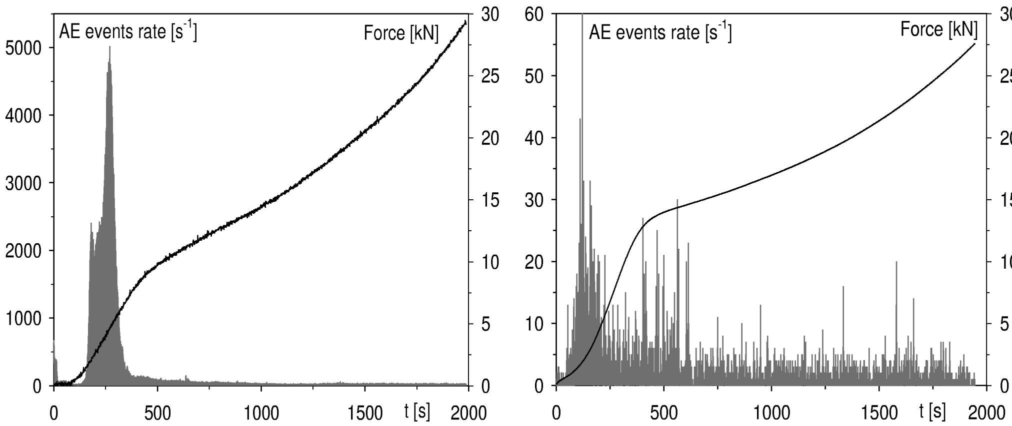

Fig. 1. Courses of AE events rate and force versus time during compression of Mg10Li alloy sample before (left) and after (right) application of HPT operation (3 rotations).

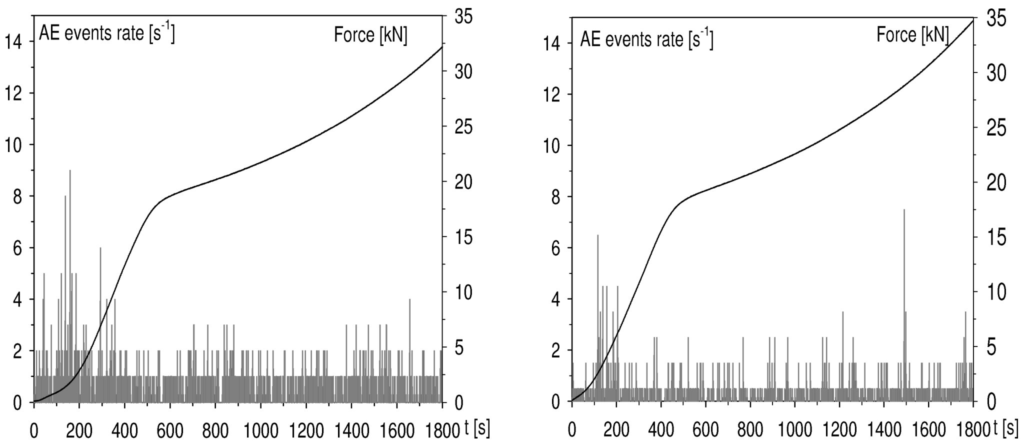

Fig. 2. Courses of AE events rate and force versus time during compression of Mg10Li1Al alloy sample after application of hpt operation (2 rotations) (left) and after application of HPT operation (3 rotations) (right).

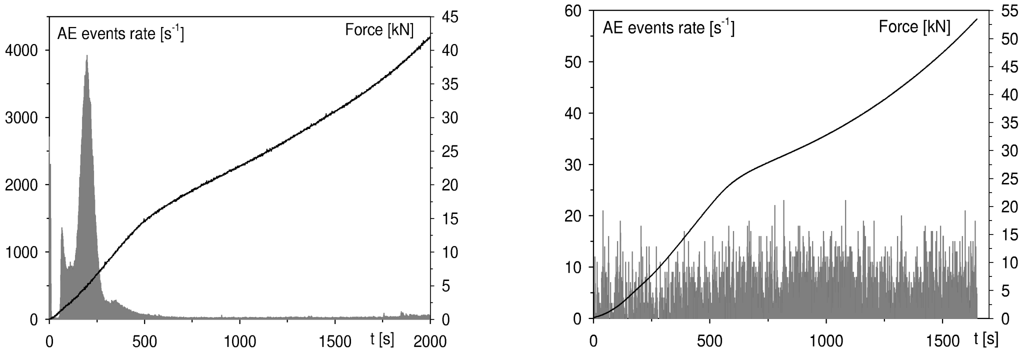

Fig. 3. Courses of AE events rate and force versus time during compression of Mg10Li5Al alloy sample before (left) and after (right) application of HPT operation (3 rotations).

3. Discussion of the results

Deformation effect using three rotations decreased the total number of AE events 30 times in case of Mg10Li alloy, 12 times for Mg10Li1Al composition and over 7 times in case of Mg10Li5Al alloy. If HPT process comprised 2 rotations – for Mg10Li1Al sample – decrease of AE events sum was lower – 7 times. The obtained results demonstrate the influence of the content of Al addition to increase both the level of AE activity in the material and to increase the limit of plasticity. It seems that this AE growth corresponded with initiation of plastic effects (microyielding) in structure of alloy material. It can be connected with evolution of dislocation system. After HPT process AE events rate decreases. Decrease of AE activity of compressed samples subjected to HPT process is closely connected with the initial structure of Mg-Li alloys consisted of grains having size of the order of several hundreds of micrometers. After HPT process, grain size decreased three orders of magnitude – to hundreds of nanometers (10^{-12} m). In majority of metallic materials grain size has crucial influence on plastic strength, as a consequence of presence of grain boundaries. This dependence is described by Hall-Petsh law. According to this a plastic strength of material is inversely proportional to square root of grain diameter. Number of grain boundaries has influence on mean free path on which dislocations can move. Investigation performed during compression process confirmed a relation between strength of the material and AE activity. AE events rate generated in compressed light metal alloys reflected the overall grain size of these materials. Registration of AE signals, being a relatively simple and fast procedure, can improve the process of determining of general structural parameters of metallic materials. The authors did not meet any notices concerning influence of mechanical strength on AE activity for Mg-Li light alloys in literature.

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