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ACOUSTIC EMISSION DURING CHANNEL-DIE COMPRESSION OF Mg-Li AND Mg-Li-Al ALLOYS AND COMPOSITES REINFORCED BY SHORT δ Al_2O_3 FIBRES

EMISJA AKUSTYCZNA PODCZAS NIESWOBODNEGO ŚCISKANIA STOPÓW I KOMPOZYTÓW Mg-Li ORAZ Mg-Li-Al WZMOCNIONYCH KRÓTKIMI WŁÓKNAMI δ Al_2O_3

The paper presents preliminary results of the investigations of the correlations occurring between the rate of the acoustic emission (AE) events and the plastic deformation mechanisms during channel-die compression of Mg-Li and Mg-Li-Al alloys, as well as the corresponding metallic matrix composites reinforced with short δ Al_2O_3 fibres. Essential qualitative and quantitative differences in the AE behaviour have been observed in the composites and in the pure alloys. The obtained results are discussed on the basis of the possible dislocation and microcracking processes and also on the basis of microstructure observations using the optical microscopy. It is suggested that the highly jumping character of AE behaviour in two-phase $(\alpha+\beta)$ Mg8Li3Al alloys is related to the twinning in α phase and to the microcracking along the interfaces, while in Mg8Li+δAl_2O_3 composites also to the fibres cracking and debonding processes, i.e. the loss of cohesion between the fibres and the matrix.

W pracy przedstawiono wstępne wyniki badań korelacji zachodzących pomiędzy tempem zdarzeń emisji akustycznej (EA) i mechanizmami odkształcenia plastycznego podczas nieswobodnego ściskania stopów Mg-Li i Mg-Li-Al oraz kompozytów na ich osnowie wzmocnionych krótkimi włóknami δ Al_2O_3. Zaobserwowano istotne różnice ilościowe i jakościowe w zachowaniu się EA zarówno w kompozytach jak i w czystych stopach. Otrzymane wyniki przedyskutowano w oparciu o możliwe procesy dyslokacyjne i procesy mikropękania jak również w oparciu o mikrostruktury obserwowane przy użyciu mikroskopii optycznej. Zasugerowano, że wysoce skokowy charakter przebiegu EA w stopach dwufazowych $(\alpha+\beta)$

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Mg8Li3Al jest związany z bliźniakowaniem w fazie α i mikropękaniem wzdłuż granic międzyfazowych a w kompozytach Mg8Li+δ Al_2O_3 także z procesami pękania włókien i debondingu, tj. dekohezji pomiędzy włóknami a osnową.

1. Introduction

The method of acoustic emission (AE) is commonly used in various fields of modern technique [1,2], most of them in the area of materials engineering, comprising mainly the problems of monitoring the development of microcracks under the influence of external load, as well as standard investigations of the deformation processes occurring during uniaxial tension of metals at ambient temperature. The AE method has been proved to be useful also in the recent investigations of strain localization connected with twinning and the formation of shear bands [3], especially in single crystals of metals with fcc structure, subjected to channel-die compression at low temperatures [4]. The application of the AE method to the investigations of the strength properties of composite materials, however, is documented to a much smaller extent. Nevertheless, the interest in composite materials continues to increase, especially what regards the light metals based composites, such as aluminium or magnesium, reinforced with various types of fibres made from materials of high mechanical strength. The first attempts at the applications of the AE method in the investigations of such materials were the tensile tests of composites with Al matrix (e.g. [5,6]). In the case of composites with Mg matrix the investigations concentrate rather on the microstructure alone and the mechanical properties attained during the tensile test [7] or the compression test [8], while the AE method is used, among other, in the investigations of the effect of cyclic changes of temperature on the microstructure of such composites (e.g. [9]).

In the present study, for the first time, an attempt has been made at the documentation of the AE effect and an explanation of the relation between this effect and the deformation mechanisms of Mg-based composites and alloys, subjected to channel-die compression at room temperature.

2. Investigation method

The procedures concerning the channel-die compression test, the AE method and the preparation of samples – described in greater detail e.g. in [3] – were also used in the here described investigations of Mg-Li and Mg-Li-Al alloys and composites reinforced with δ Al_2O_3 short fibres, obtained from technical SAFFIL in cooperation with IMMM SAS in Bratislava. Samples of composites, obtained using the technology described in detail in [8], in the form of cubes with 10 mm edge, were subjected to compression tests in a testing machine INSTRON-6025, equipped additionally with a specially prepared channel-die, which ensured plastic flow only in the direction of compression and in the direction parallel to the die axis; there was no deformation in the direction transverse to the die walls (plane state of strain). The traverse speed of the testing machine was always the same and was equal to 0.05 mm/min.

Simultaneously with the registration of the external force F, there was measured the AE parameter as the rate of the AE events $\Delta N_z/\Delta t$. A broad-band piezoelectric sensor enabled to record the acoustic pulses in the frequency range from 100 kHz to 1 MHz. The contact between the detector and the sample was maintained by means of a steel rail in channel-die which formed a natural acoustic wave-guide. In each of the performed tests the number of AE events was recorded within the same time interval $\Delta t = 4$ s. Similarly, the total amplification of the acoustic signals was 86 dB, and the corresponding optimal threshold voltage of the discriminator remained within the interval of the values 1.17 – 1.20 V. In order to minimize the undesired effect of friction against the channel walls, each sample was covered with a teflon foil.

Moreover, after each compression test, there have been carried out microstructure observations using the standard technique of optical microscopy. In this way, in many cases, besides the acoustic characteristics (rate of AE events as a function of time) and the mechanical characteristics (work-hardening curve in the version: force-time), there have been presented the respective micrographs, illustrating the most essential elements of the microstructure, and the effects of its evolution resulting from the operation of the respective mechanisms of plastic deformation and the processes of microcracking.

3. Measurement results and discussion

The results were the subject of an analysis and discussion using also the phase diagram of the binary system of magnesium-lithium (Fig.1), since in the examined

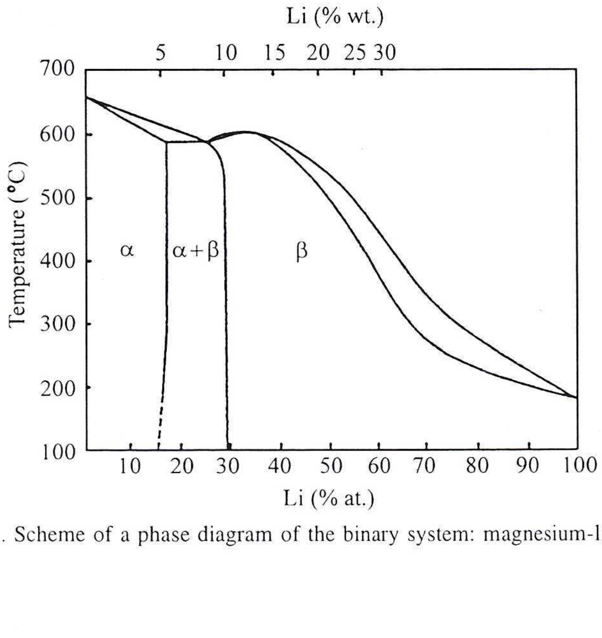

Fig.1. Scheme of a phase diagram of the binary system: magnesium-lithium

materials the concentration of lithium (%wt.) corresponded to the range of existence of three various alloys of different structure: single-phase alloy α-Mg4Li of hexagonal structure, two-phase alloy $(\alpha+\beta)$-Mg8Li, and single-phase alloy β-Mg12Li of bcc structure. Earlier suggestions of the authors presented in the studies [11–13] were also taken into consideration.

3.1. Acoustic emission (AE) in Mg-Li-Al + δ Al_2O_3 composites

Figures 2 and 3 illustrate the behaviour of AE and the external load as a function of the duration of the channel-die compression test of composites with Mg4Li3Al (Fig.2a) and Mg4Li5Al (Fig.3a) matrices. On the right side of each of these figures there are presented (Figs 2b and 3b), respectively, the microstructures of the composites after deformation, revealed by the traditional method of optical microscopy. When comparing the AE behaviour it can be noticed that the AE activity of a composite with higher Al content (Fig.3a) last longer and demonstrate more rapid changes in the number of events when compared with the activity of a composite with a smaller content of Al (Fig.2a). However, the level of the event rate (of the order 8×10^4 at most) as well as the course of the work hardening curves (slight differences in the slope of the linear range) are of similar character, which is reflected also in the observed microstructures (Figs 2b and 3b).

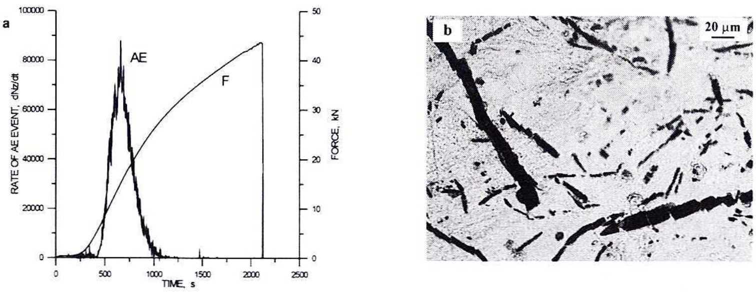

Fig. 2. Behaviour of AE and the external force (a) during channel-die compression of the composite Mg4Li3Al + δ Al_2O_3 and its microstructure (b) after deformation

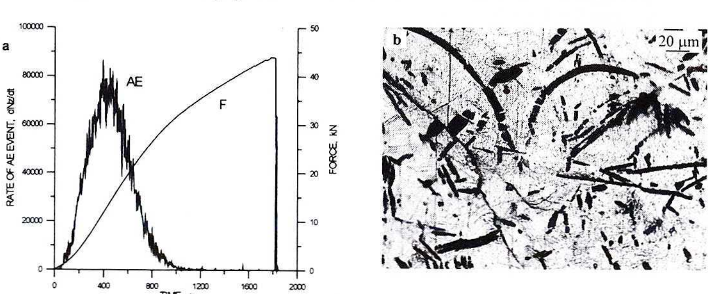

Fig. 3. Rate of AE events and the external force (a) during channel-die compression of the composite Mg4Li5Al + δ Al_2O_3 and its microstructure (b) after defornation

A characteristic feature of both microstructures is a distinctly visible fragmentation of the δ Al_2O_3 fibres, formed as a result of their cracking under the influence of mechanical stresses. It is very probable that the cracking of the fibres is a significant contribution in the form of sudden jumps of AE, against the background of the observed wide maximum of the rate of AE events, whereas the longer activity of AE, connected with the rapid jumps of AE, is related rather with the planar random distribution of the fibres. Namely, the fibre planes in a composite containing 5% of Al were perpendicular whereas in a composite containing 3% of Al they were parallel to the direction of compression. Thus the number of fibres, being the obstacles for active dislocations on shear planes, is statistically two times greater in the latter case than in the former one, which in consequence, limit the processes of generation and surface annihilation of dislocations which are the basic AE sources in metals. Such a supposition will be confirmed in further consideration.

In the literature (see e.g. [10]) there are considered still other mechanisms of cracking which may have a substantial influence on AE behaviour. Besides the formation of microcracks in the metallic matrix itself, loss of the cohesion between the fibres and the matrix (debonding) may play an essential role. Obviously, the dislocation processes, as it is known, have an essential influence on AE behaviour in metallic materials, hence in metallic matrix composites such processes as the generation of dislocations within the region of the yield point, dislocation annihilation connected with the formation of steps on the sample surface or the formation of shear bands and the twinning processes must be taken into consideration first of all.

3.2. AE in single – phase Mg-Li alloys and composites

Figures 4 and 5 show the behaviour of the AE and the external force as well as the corresponding microstructures after deformation for pure single-phase α-Mg4Li alloy (Fig.4) and for Mg4Li+δ Al_2O_3 composite (Fig.5), respectively. Characteristic is here a considerably higher level of the rate of AE events (even more than 10^6 AE events during 4 sec; the actual values are beyond the scale) and the evidently longer period of the activity of AE sources in pure alloy (Fig.4) in comparison with the composite where this level, although high, does not exceed much the value 10^5 (also beyond the scale in Fig.5) in a distinctly shorter time. The shorter period of AE activity is connected with presence of fibres, which, being the additional obstacles for moving dislocations, limit the activity of AE sources as it was suggested in Section 3.1.

The very high level of AE in pure alloys can be attributed to the superposition of AE events generated by dislocations not only in the basal (easy) slip systems, but also in the pyramidal systems, since the presence of lithium atoms in the hexagonal phase α modifies with advantage the ratio c/a, increasing the chance of the activation of these systems. Moreover, it may be suggested that the more jump-like changes on the rate of AE events in the final period of AE activity are connected with the formation of twins (Fig.4b), which also contribute to the high level of AE.

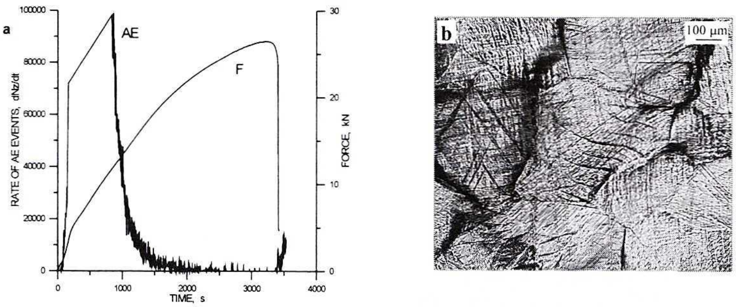

Fig. 4. AE and the external force (a) during channel-die compression of single-phase alloy α-Mg4Li and its microstructure (b) after deformation

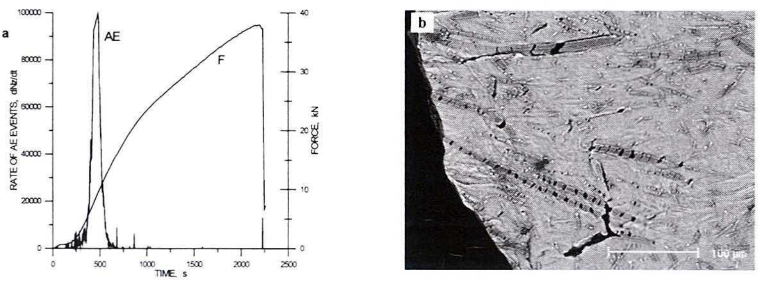

Fig. 5. AE and the external force (a) during channel-die compression of the composite Mg4Li5Al + δ Al_2O_3 and its microstructure (b) after deformation

The behaviour of AE in a composite (Fig.5) is similar to that observed in the case of Mg4Li3Al + δ Al_2O_3 composite (Fig.2a), although the AE peaks within the main maximum are here less frequent. Similarly, there are observed the cracks of the fibres (Fig.5a) as well as the cracks connected with the loss of cohesion between the fibres and the matrix (debonding). It is suggested that two, still remarkable AE peaks at the final stage of AE activity may here (Fig.5a) be associated with the processes of debonding.

3.3. AE in two – phase alloys and composites

Figures 6 and 7 show the courses of AE and compressive force as well as the microstructures for two-phase alloy ($\alpha+\beta$)-Mg8Li (Fig.6) and Mg8Li3Al alloy (Fig.7), respectively; for the sake of comparison in Fig.8 there are shown the behaviour of AE and the force for Mg8Li + δ Al_2O_3 composite (Fig.8a), and for the single-phase alloy α-Mg12Li (Fig.8b). It can be noticed that the level of the rate of AE events in two-phase alloys (Figs 6–7) is already evidently smaller (below 10^5) in comparison with the respective level in a single-phase alloy α (Fig.4a), or even in a composite based on the matrix of this alloy (Fig.5b). This is comprehensible when taking into consideration that the dislocation sources in active slip systems and the twinning mechanisms operate only within one phase α (Fig.7b). Characteristic is here the highly jump-like course of AE,

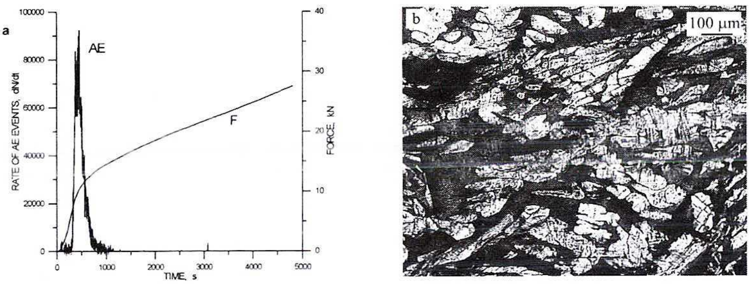

Fig. 6. AE and the external force (a) during channel-die compression of two-phase alloy ($\alpha+\beta$)-Mg8Li and its microstructure (b) after deformation

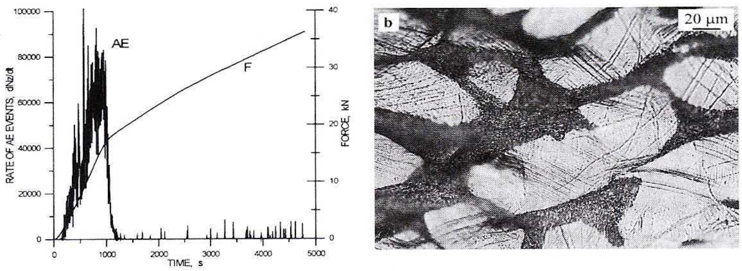

Fig. 7. AE and the external force (a) during channel-die compression of Mg8Li3Al alloy and its microstructure (b) after deformation

which in Mg8Li3Al alloy (Fig.7a) is very intensive until it reaches the maximal level of AE, whereas in Mg8Li alloy (Fig.6a) it take places on a rather small degree near the maximal level of AE. A hypothesis has been put forward that such behaviour of AE is connected with the nucleation of microcracks along the phase boundaries (Figs 6b, 7b). It should be also noticed that in Mg8Li3Al alloy the AE activity remains at a rather low level till the end of the compression test, in contrast to Mg8Li alloy, in which after the main maximum of AE activity there occurs practically acoustic silence.

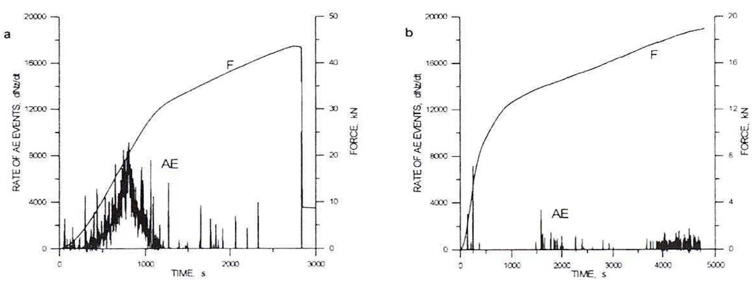

Fig. 8. AE and the external force during channel-die compression of Mg8Li+δ Al_2O_3 composite (a) and the single-phase alloy β-Mg12Li (b)

When analysing the AE behaviour, presented in Fig.8 for the $Mg8Li+\delta\,Al_2O_3$ composite, compared with AE progress in $Mg4Li+\delta\,Al_2O_3$ composite (Fig. 5a), one can become convinced that the AE peaks on the background of the main maximum of AE activity are related with the cracking of fibres, while the following series of single AE peaks (near 2000 s, Fig.8a) is the result of the debonding processes. The AE level, however, is here considerably lower (of the order of 8×10^3), comparable with the level observed in the single-phase β-Mg12Li alloy (Fig.8b). Moreover, besides the main AE maximum (connected generally with the region of yield point), there can be here observed two distinct series of AE peaks in the region of advanced work hardening. A surprising low level of AE in β alloy in comparison with the level in α alloy (Fig.4a) is preliminarily related to the high plasticity of the β phase. A more detailed description of AE behaviour in these alloys, however, will be possible after the investigation results of both composites on their basis as well as of β alloys of various aluminium content have been obtained. Such investigations are planned in the nearest future.

4. Summarizing remarks and conclusions

The presented results demonstrate great variation of the behaviour of acoustic emission (AE), both in the alloys alone and in the corresponding metallic matrix composites. The undertaken preliminary studies aimed at the explanation of the correlation between the rate of AE events and the deformation mechanisms should enable to identify and to monitor, using AE method, the processes of strain localization (e.g. twinning) and the processes of microcracking in the alloys and composites (cracking along the phase boundaries, fibre cracking, debonding). The most important results can be summarized as the following conclusions:

– A considerably shorter period of activity of AE sources in composites when compared with the activity in pure alloys is due to the presence of fibres which limit the processes of the generation and annihilation of dislocations which are efficient sources of AE in metals.

– Very high level of AE in single-phase α alloy is the result of the superposition of AE events generated by active dislocations in basal slip systems and in pyramidal slip systems, as well as in the course of twinning.

– It is assumed that high AE peaks, appearing in the composites on the background of the main maximum of AE activity are related with the cracking of fibres, and the series of single AE peaks, following this maximum, may be generated by debonding processes.

– A hypothesis is put forward that the highly jump-like character of AE behaviour in two-phase $(\alpha+\beta)$ alloys on the background of the main maximum of AE activity is connected with the processes of microcracks nucleation along the phase boundaries.

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