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ACOUSTIC EMISSION IN COMPRESSED Mg-Li AND Al ALLOYS PROCESSED BY ECAP, HPT AND ARB METHODS

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In the paper there are presented the results of investigations of the relations between acoustic emission (AE) and the plastic strain mechanisms during channel-die compression of materials, based on both Mg-Li and Al alloys, having ultra fine-grained (UFG) or nanocrystalline structure obtained using the technique of equal channel (of both quadratic and circular section) angular pressing (ECAP) as well as the technique of high pressure torsion (HPT). Also the AE in compression and tensile tests of UFG (nanocrystalline) Al alloys obtained by accumulative roll-bonding (ARB) method have been investigated. The results obtained using a new generation AE analyzer are compared with those obtained for similar materials but not subjected to ECAP, HPT and ARB processing. Moreover, the wavelet analysis of the detected AE signals based on the acoustic maps (acoustograms) and spectral characteristics has been carried out and the AE behaviour is discussed in the dislocation aspects of both plastic strain mechanisms and possible superplastic flow in UFG or nanocrystalline materials.

Keywords: acoustic emission, Mg-Li-Al alloys, compression test, nanocrystalline and/or ultra fine-grained (UFG) structures, strain mechanisms, dislocations, intensive strain methods (ECAP, HPT, ARB).

1. Introduction

In the last decade more and more attention has been given to obtaining nanocrystalline materials on account of their excellent mechanical properties, such as great strength and plasticity or even superplasticity occurring in condition of relatively not high temperatures [1].

The methods of intensive deformation [1–3] have become more and more widely used to obtain microstructure refinement as they allow to obtain massive samples of metals ready for further treatment. This refers in particular to packed rolling with bonding, the so called ARB (Accumulative Roll-Bonding) method [4–6]. There are also known products obtained on industrial scale by the method of channel die compression ECAP (Equal Channel Angular Pressing) [1, 2, 7]. The method of torsion under high pressure HPT (High Pressure Torsion [1]) is the least known since obtaining the high pressure alone is a difficult problem. The above methods are used for the refinement of the microstructure to obtain ultra fine-grained (UFG), nano-crystalline grain size leading to the increase of strength and ductility of the material.

Alloys based on magnesium with lithium as the highest from among the known metallic construction materials, and particularly the composites based on alloys reinforced with ceramic fibres are very attractive materials from the point of view of their application, e.g. in the automobile industry as the bodies of engines. Mg-Li alloys may occur in three different forms. The mechanical properties of the hexagonal (*hcp*) α phase are worse than those of the regular (*bcc*) β phase, which is characterized by very good machinability and weldability and, at the same time, by considerably lower acoustical efficiency during deformation [8, 9]. Mg10Li alloys are two-phase alloys and occur as a mixture of $\alpha + \beta$ phases. Alloy addition, e.g. 5%Al increase somewhat the density of Mg10Li5Al alloy, but they improve the mechanical strength of the alloy.

The aim of the study is an attempt to explain the correlations between the mechanisms of plastic deformation and the AE phenomenon and discussion of the possible connection of AE with the phenomenon of superplasticity in UFG aluminium alloys of PA2 type, obtained after the ARB operation, as well as aluminium alloys of 6060 and 2014 type and Mg10Li and Mg10Li5Al alloys obtained both after the ECAP as well as after the HPT methods. This has been inspired by the fact that strong tendencies for superplastic flow and changes in the activity and intensity of AE have been observed earlier [10] in UFG Mg8Li and Mg12Li alloys subjected to compression after the ECAP operation.

Theoretical basis of the method of wavelet analysis, in a shortened version has been presented in the studies [9, 11], where it has been used for the first time for composites on the basis of Mg-Li-Al alloys, reinforced with ceramic fibres and for silver single crystals [9, 11], in order to identify the processes of twinning and formation of shear bands.

However, at this still initial stage of investigations the discussion of the possible relations between AE and superplasticity has a preliminary character and it has been here carried out first on the basis of the measurement results of the most often used parameters: i.e. RMS (Root Mean Square) of AE signals and on the number of AE events (the rate of AE events).

2. Experimental procedures

Figure 1 shows the scheme illustrating the method of channel die extrusion ECAP [7]. The parameters of the installation have the following values: $b = 10$ mm, $a = 30$ mm, angle $\alpha = 31.3°$ or $\alpha = 90°$. Equivalent strain (for square cross-section) is equal to $\varepsilon_n = 0.5922n$, where n – number of passes. For the angle $\phi = 90°$ and $\alpha = 0°$ it amounts to $\varepsilon_n = 0.9069n$ [7]. Figure 2 shows the scheme of the HPT method of torsion under high pressure [1].

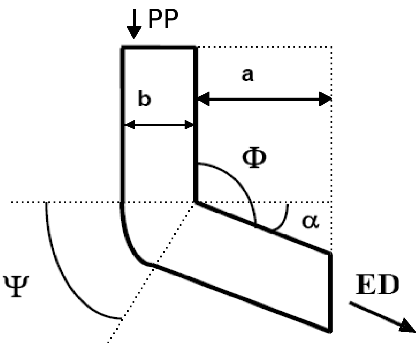

Fig. 1. Scheme of ECAP angular extrusion: ED – direction of outflow, PP – direction of the punch pressure.

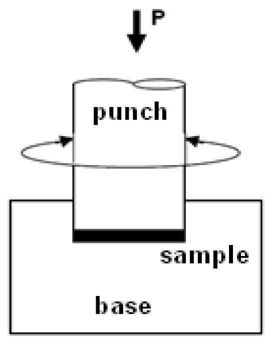

Fig. 2. Scheme of torsion under high pressure HTP.

The sample is a roll with R radius of the base and the height l. The dilatational strain γ after N rotations is equal to $\gamma = (2\pi RN)/l$, and the equivalent strain $\varepsilon_N = \gamma/1.73$. The ARB method is discussed also in this volume, but in another our paper [12].

The Mg10Li and Mg10Li5Al alloys were prepared in cooperation with the Institute of Materials and Machine Mechanics of the Slovak Academy of Sciences in Bratislava. 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.

Samples to be used for ECAP tests (for circular cross-section) had the shape of rolls with the diameter 20 mm and the height 30$\div$40 mm; samples to be used in HPT tests had the shape of discs of the diameter 10 mm and the thickness 3$\div$5 mm. Samples intended for compression had the shape of cubes with the edge not greater than 10 mm in case of ECAP or the shape of square plates with the side 10 mm and the thickness 1 mm, cut in the case of ARB from samples prepared earlier for the tensile tests. The discs after HPT, intended for the compression tests, had the thickness of the order of 1$\div$2 mm.

All compression tests in a channel-die were carried out using the new testing machine INSTRON–3382. The rate of the machine traverse in the compression tests was 0.05 mm/min.

Simultaneously with the registration of the external force F there were measured the AE parameters in the form of the rate of AE events, or in the form RMS – the effective value of voltage of the registered AE signal. A broad band piezoelectric sensor allowed to register the acoustic pulses in the frequency range from 10 kHz do 1 MHz. The contact of the sensor with the sample was maintained by means of a steel plate in the channel-die. In each compression test the basic AE parameters, i.e. the single AE events, their energy, frequency and duration were continuously detected. Other important parameters of a new type of AE measuring system were: total amplification 70 dB, threshold voltage 0.5 V. In order to eliminate the effects of friction each sample was covered with Teflon foil.

3. Results and discussion

The paper presents selected results of the investigations of AE behaviour during compression tests of Mg-Li alloys and Al alloys before and after treatment by the ECAP, ARB and HPT methods. Figure 3 shows, by way of example, the course of RMS AE parameter and the external force during compression tests of Al alloys of 6060 type, after two- (Fig. 3a) and four-fold (Fig. 3b) treatment in ECAP channel of circular cross-section. It is clearly visible that plasticity and RMS increase with the increase of the multiplication factor of the sample pressing (the reduction degree), i.e. with the increase of the grain refinement.

a) b)

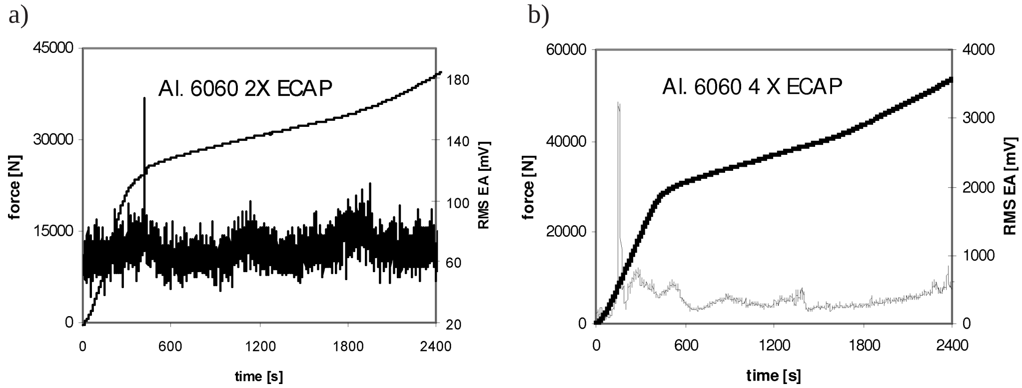

Fig. 3. Courses of AE and force during Al 6060 alloy compression after two- (a) and four-fold (b) ECAP treatment.

Figure 4 shows similar graphs, but for Al alloy of PA2 type, obtained after $n = 5$ (Fig. 4a) and $n = 6$-fold (Fig. 4b) packet rolling ARB. Such samples were characterised by maximum plasticity in tensile tests, which has been shown in another paper [13]. It can be seen that the plasticity remains on a comparable level – at the about 1200 s the force is in both at the level of about 40 kN. On the other hand the RMS values are somewhat higher for $n = 6$ (greater reduction) which is more clearly seen within the

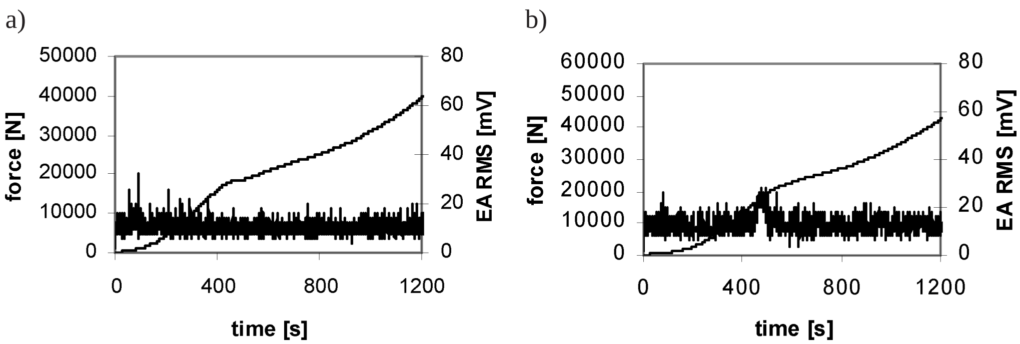

Fig. 4. Courses of AE and force during Al PA2 alloy compression after five- (a) and six-fold (b) application of ARB operation.

area 400÷600 s in Fig. 4b. Thus, also here the tendency is similar as in the previously discussed case of 6060 alloys (Fig. 3): with increasing reduction in the ECAP and ARB processes there increase the activity and the intensity of AE. On the other hand, in case of Mg10Li and Mg10Li5Al alloys the AE behaviour is varied. Hence, in Fig. 5 there are presented the results obtained for Mg10Li alloys compressed before (Fig. 5a) and after (Fig. 5b) application of the HPT operation, while in Fig. 6 – for Mg10Li5Al alloys, also before (Fig. 6a) and after (Fig. 6b) HPT operation.

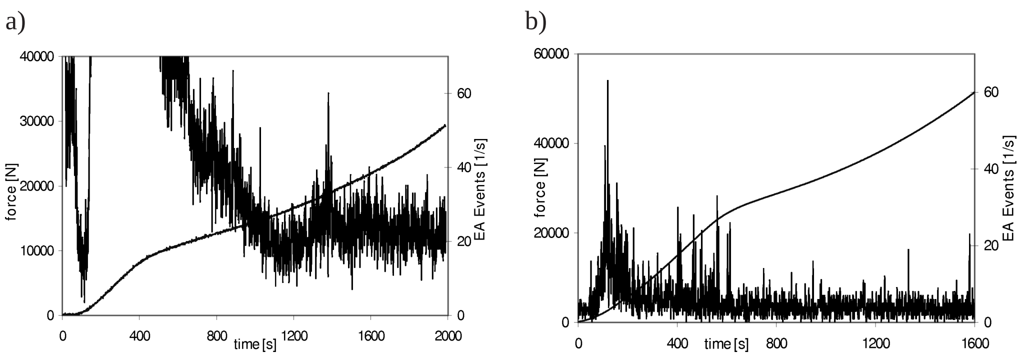

Fig. 5. Courses of AE and force during compression of Mg10Li alloys before (a) and after (b) application of HPT operation.

It can be observed that for Mg10Li 5Al alloys the RMS values in the region of advanced deformation (here of about 600 s by convention) are however on a lower level for alloy after HPT (Fig. 6b) than for the alloy before HPT (Fig. 6a). The falling tendency of AE is better visible for Mg10Li alloys in case when the parameter of the number of AE events is drown. This is shown in Fig. 5, also above 600 s; in the region below 600 s (Fig. 6a) the AE behaviour is typical for these alloys and it has been discussed extensively in another paper [9].

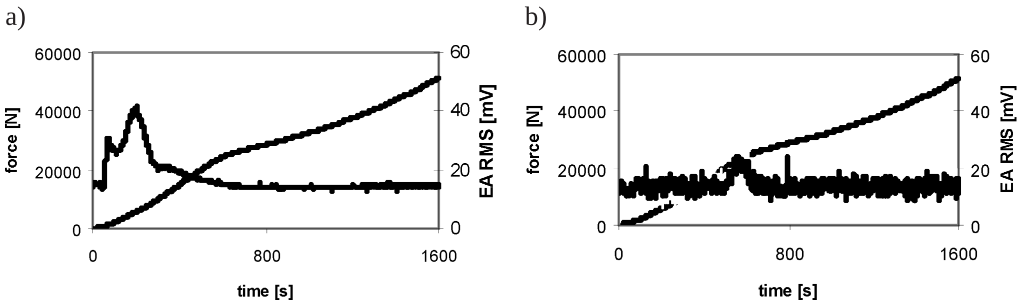

Fig. 6. Courses of AE and force during compression of Mg10Li5Al alloys before (a) and after (b) application of HPT operation.

It should be noticed that it has been observed [10] that AE in Mg8Li and Mg12Li alloys decreases after ECAP operation, the result of which was the increase of plasticity with distinct refinement of the structure. This interpreted in favour of the suggestion that in the state of increased plasticity the AE shows a falling tendency. However, the investigations carried out using the new AE analyser for the same alloys [10] before and after four-fold ECAP operation have shown that the AE level is definitely higher after ECAP operation than in the initial state. This may be the effect of a different temperature (70°C) of extrusion. At the present state of investigations it is difficult to interpret the above dependences. It is necessary to obtain more information by systematic investigations, concentrated on one method, e.g. HPT.

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