ARCHIVES OF ACOUSTICS
32, 4, 955–962 (2007)

ACOUSTIC EMISSION AND THE PORTEVIN–LE CHÂTELIER EFFECT IN TENSILE TESTED Al ALLOYS PROCESSED BY ARB TECHNIQUE

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(*received July 15, 2007; accepted October 2, 2007*)

The paper presents the investigations of the relation between the acoustic emission (AE) and the Portevin–Le Châtelier (PL) phenomena occurring in tensile tested two kinds of aluminium alloys: not-predeformed and predeformed earlier using the technique of accumulative rolling banding (ARB). There have been found essential correlations between AE and PL effects in ARB not-predeformed alloys. The tensile tests for ARB predeformed alloys were performed on a series of samples of various degree of work hardening and it has been observed that the correlations between the AE and PL effects are not so pronounced as in the case of ARB not-predeformed alloys. The results of AE measurements obtained using a new software allowed additionally to carry out the spectral analysis of AE signals and, in consequence, to determine the acoustic maps (acoustograms) and the spectral characteristics which are very useful in the discussion of the relations between the non-homogeneous strain mechanisms of the PL effect and the mechanisms of AE events generation. The results are discussed in the context of the existing dislocation models of the PL effect and the theoretical concepts of AE sources.

Keywords: acoustic emission (AE), Portevin–Le Châtelier (PL) effect, tensile test, dislocations, strain mechanism, nanocrystalline and/or ultra fine-grained structure, accumulative roll-bonding (ARB).

1. Introduction

The methods of intensive deformation are more and more widely applied to obtain the refinement of the microstructure and to produce ultra-fine grained (nanocrystalline) grain size leading to the increase of mechanical strength and ductility of the processed material. Such methods allow also to obtain bulk samples of metals, ready for further treatment. This refers in particular to the method of pack rolling with bonding, i.e. the so-called accumulative roll-bonding (ARB) [1, 2].

The aim of the study is the application and analysis of the ARB method in connection with the investigations of the relations between the behaviour of acoustic emission (AE) and the course of the phenomenon of the Portevin–Le Châtelier (PL) nonhomogeneous deformation in Al alloys of PA2 type before and after ARB treatment. Moreover, to our knowledge, there are no reports available in literature on the relation between the PL and AE effects in ultra fine-grained (nanocrystalline) alloys.

There exist some parameters characteristic of the PL effect. Two from among them: the critical strain ε_c and the waiting time t_w sufficiently characterize the essence of the phenomenon (see e.g. [3]). The waiting time t_w informs how long the dislocations must wait to obtain the activation energy Q in order to overcome the obstacles on the path of their motion. Its magnitude is contained in the know formula of Orowan for the strain rate: $\dot{\varepsilon} = b\rho L/(t_w + t_f)$, where b – magnitude of the Burgers vector of dislocation, ρ – density of the mobile dislocations, and t_f – flying time, i.e. the time of the dislocation passage at the distance L between the obstacles, e.g. forest dislocations in the case of metals of FCC structure. The PL effect begins when the strain reaches the critical value ε_c, i.e. when the waiting time t_w attains the value of the aging time t_a. Then all the dislocation sources are efficiently blocked by Cottrell atmospheres. Then the relation $t_w \gg t_f$ is satisfied and the strain rate satisfies the relation: $\dot{\varepsilon} = b\rho L/t_w = \dot{\varepsilon}_o \exp(-Q/kT)$, where $\dot{\varepsilon}_o$ – material constant, k – Boltzmann constant, T – absolute temperature, Q – activation energy.

2. Experimental procedure

Figure 1 shows the scheme of the ARB technique. Purified and degreased surfaces of two sheet plates are folded and fastened, next heated and rolled to the reduction $z = 50\%$. The sheet obtained after rolling is cut into halves and subjected to the same procedure as before. The procedure may be repeated several times. For example a sheet plate with the thickness g_o, subjected in succession to rolling in succession n time to the reduction $z = 50\%$, i.e. after n passes, will have the thickness $g_n = g_o/2^n$, and the total reduction will be equal to $z_n = 1 - g_n/g_o = 1 - 1/2^n$.

The tensile tests were carried out with tenfold plane specimens using the standard INSTRON-6025 type machine. In each test the rate of the traverse of the testing machine was 2 mm/min. The two identical series, assigned also for the test of the repeatability of the measurements results, each of six specimens, after $n =$ 1, 2, 3, 4, 5 and 6 passes of

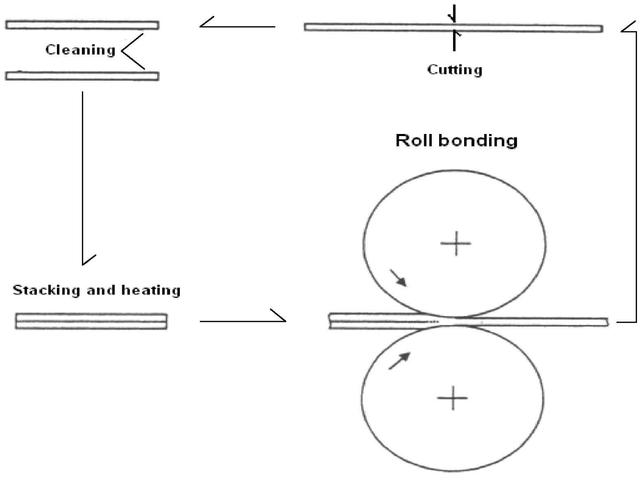

Fig. 1. Scheme of the accumulative rolling ARB.

ARB process were examined using the tensile test and the AE method. Each specimen was of the gauge length $l_0 = 90$ mm (overall length $l_c = 105$ mm), $b_0 = 20$ mm width and $a_0 = 3.50$ mm thickness.

For each tested sample, simultaneously with the measurement of the external tensile force, 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. The broad-band piezoelectric sensor was arranged to register the AE waveforms within the range from 5 to 200 kHz; for more details about many other possibilities of a new AE analyser see also our other papers [3–5].

3. Results and discussion

The paper presents selected results of the first investigations of the relations between the mechanical properties, mainly such as strength and the strain mechanisms and the AE signals generated in a tensile test of aluminium alloys of PA2 type before and after ARB process. In Fig. 2 it is shown that there appear essential correlations between the AE and the PL effects in not-predeformed alloys. On the other hand, in case of alloys, predeformed by the ARB method, the tensile tests were carried out on six samples with various reductions obtained after successive passes, numbered from $n = 1$ to $n = 6$. The tensile curves in the version: force – time, are shown in Fig. 3. On the basis of other results [6], not presented here, obtained for identical samples but of smaller dimensions and subjected to ARB operation from $n = 1$ to $n = 10$, it has been observed that the maximum plasticity occurs in samples obtained after the passes $n = 5$ and $n = 6$.

Figure 4 shows the behaviour of force and AE during tension of PA2 alloy obtained after $n = 6$ passes of ARB. It can be seen that the correlations between the PL and AE

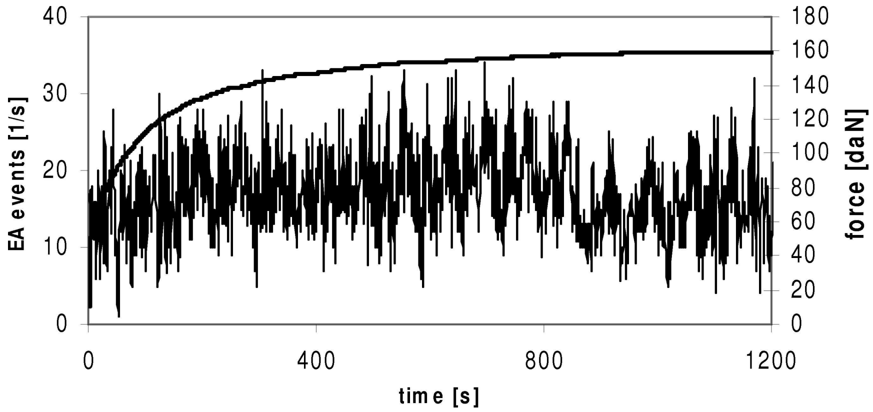

Fig. 2. Correlations between the AE behaviour and the course of force during the PL effect in a tensile test of PA2 alloy before the application of ARB operation.

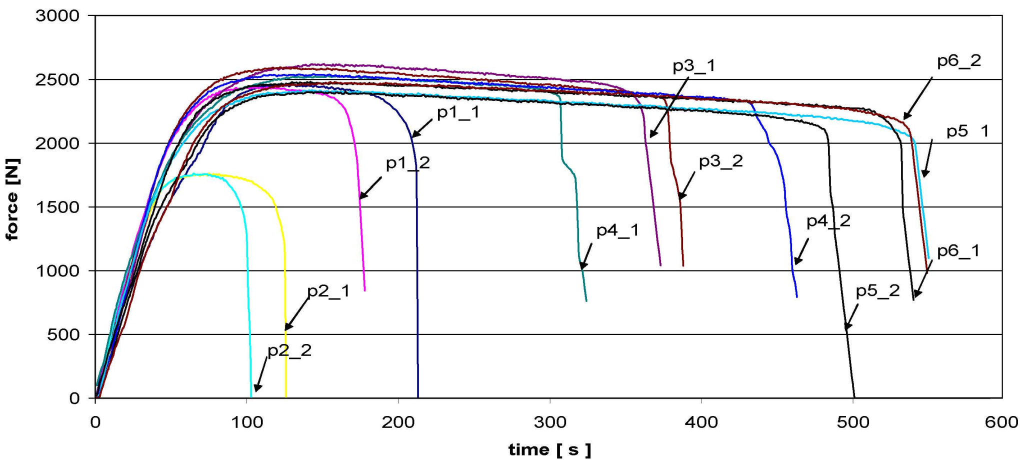

Fig. 3. Tensile curves in the force-time version for PA2 alloys obtained after $n = 1$ to $n = 6$ passes by means of the ARB method. There can be seen two series of curves illustrating good repeability of the measurements results.

effects continue to occur: to the peaks of the rate of AE events there correspond local drops of force (although at this scale not very well visible), characteristic for the PL effect. However, both the activity and the intensity of AE as well as the values of the local drops of force are no longer so distinct as in the case of not-predeformed samples (Fig. 2). Thus, it can be said that both the PL and the AE effects in samples of more refined grain size (nanocrystalline) show the tendency to disappear.

Due to the application of modern software there has been also carried out the spectral analysis of AE signals enabling the preparation of acoustic maps (acoustograms). Figure 5 shows, by way of example, such an acoustogram for a sample after $n = 6$ passes by the ARB method. It should be especially noticed that it is clearly shown here that the correlations between the PL and AE effects occur in the frequency range of AE

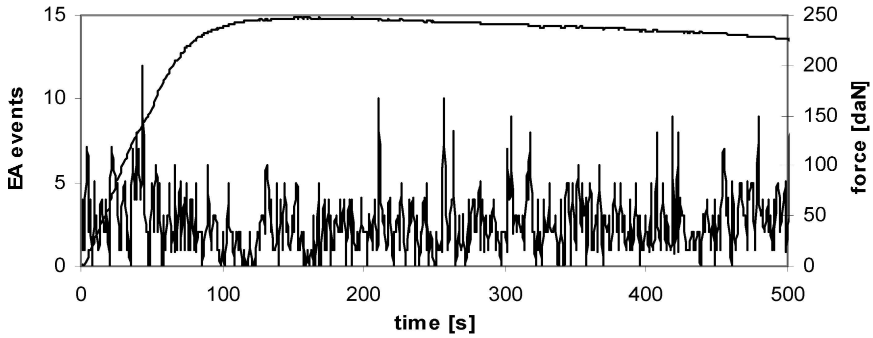

Fig. 4. Correlations between AE behaviour and the course of force during the PL effect in a tensile test of PA2 alloy predeformed by $n = 6$ passes of the ARB method.

signals above 17 kHz (except the line at about 360 s), which seems to be a very characteristic, never noticed earlier, feature of the PL effect. In all other cases examined so far by the authors (mono- and polycrystalline metals, alloys and composites) in which the PL effect does not appear, the discussed frequency range is considerably lower – most often below 8 kHz.

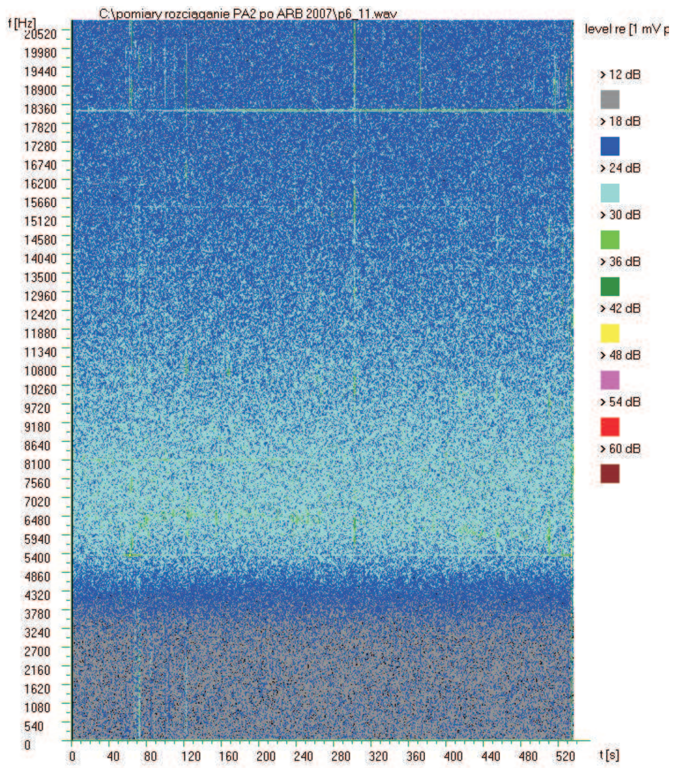

Fig. 5. Acoustic map of AE signals generated during tension of PA2 alloy after 6 repetitions of ARB operation.

Most of the models of PL effect (e.g. [7–9]) are of phenomenological character and none of them explain clearly the physical mechanisms of the formation and propagation of the related deformation bands and which would be coherent with the models of the sources of AE. The presented results are briefly discussed below in the context of the dislocation models of the PL effect reported in literature (e.g. [10, 11]) and the theoretical concepts concerning the source of AE generation during plastic deformation of metals (e.g. [3, 12]).

In accordance with a simple dislocation-dynamic (DD) model of the PL effect [11], each local drop of the external force on the work-hardening curve (Fig. 6a) is connected with unlocking of the dislocation sources in a certain localized area of the sample. The consequence is the formation of a slip band (Fig. 6b) which continues to propagate (Fig. 6c) until the waiting time t_w reaches again the value of the aging time t_a. The strain rate in the slip band $\dot{\varepsilon}_d$ is greater than the rate of the homogeneous strain $\dot{\varepsilon}$ due to the high dislocation dynamics (DD). Accordingly, on force-time curve a local drop must occur (Fig. 6a), since, according to the well-known equation of Penning: $K^{-1}\mathrm{d}\tau/\mathrm{d}t+\dot{\varepsilon}_d = \dot{\varepsilon}$, there occurs the relation $\mathrm{d}\tau/\mathrm{d}t < 0$ for $\dot{\varepsilon}_d > \dot{\varepsilon}$; K – coefficient of rigidity of the system: machine – sample.

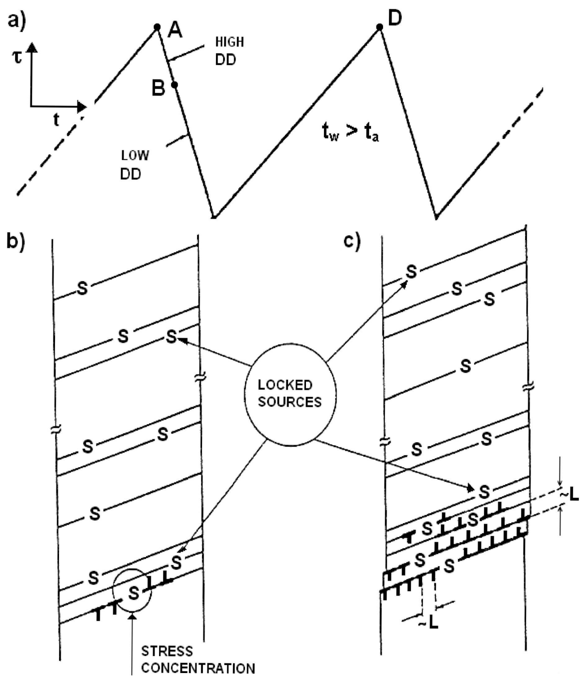

Fig. 6. Simple DD model of the PL effect [11]: a) jump-like drop of force, b) localization and nucleation of a slip band and c) propagation of a slip band.

Simultaneously with the above process there takes place the generation of AE events both due to the acceleration as well as annihilation of dislocations. Dislocations generated from the Frank–Read (FR sources may attain very great accelerations resulting from the interactions of the dislocation-dislocation type. However, there are more premises [3] maintain that the contribution to AE signals due to annihilation is considerably higher than that resulting from acceleration. Moreover, the contribution from the annihilation of the dislocation segments when the dislocation loops are bearing off from the FR source is intensified and dominated by the processes of the surface annihilation of dislocations, such as it takes place e.g. in the case of the formation of dislocation steps on the sample surface due to the formation of slip lines and slip bands or the shear microbands. This observation is in accordance with the results obtained by other authors [13], who have clearly demonstrated the strong influence of the surface on the phenomenon of acoustic emission during plastic deformation of metals.

4. Conclusions

1. PL and AE effects in nanocrystalline alloys show the tendency to disappear.
2. Correlations between the PL and AE effects occur in some cases in the frequency range above 17 kHz, where as in metals not generating the PL effect they occur in a lower range – usually below 8 kHz.
3. Correlations between the PL and AE effects can be explained on the basis of a simple dislocation-dynamic model of the PL effect.

Acknowledgment

The study was financially supported from the research project of the Polish Committee for Scientific Research No 3 T08A 032 28 and also partly from the research project of the Polish Ministry of Science and Higher Education No N507 056 31/128.

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