Transactions of the VŠB – Technical University of Ostrava, Mechanical Series
No. 2, 2010, vol. LVI
article No. 1802

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APPLICATION OF ACOUSTIC EMISSION METHOD DURING HIGH CYCLE FATIGUE OF ALUMINIUM ALLOY

VYUŽITÍ METODY AKUSTICKÉ EMISE PŘI VYSOKOCYKLOVÉ ÚNAVĚ SLITINY HLINÍKU

Abstract

This paper deals with evaluation of degradation processes, which occur at cyclic loading of samples of Al alloy EN AW-2017/T4. NDT procedure – acoustic emission (AE) method was used for detection of microstructure changes during stages of fatigue damage accumulation and micro-cracks initialisation. This measurement was completed with analysis of loading frequency changes of the fatigue test device. AE signal records obtained with use of the newly developed AE analyser with continual recording of signal are commented and showed other parameters of AE sample in detail.

There is also presented a new method of mechanical clamping of the AE sensors used at fatigue tests. Thanks to the placing of the AE sensors in proximity of the area of supposed fatigue crack the significant improvement of the quality of AE data was observed during the fatigue tests.

Abstrakt

Článek se zabývá možnostmi hodnocení degradačních procesů, které se objevují při cyklickém zatěžování zkušebních vzorků z Al slitiny EN AW-2017/T4. Pro detekci změn mikrostruktury v průběhu akumulace poškození a iniciace mikrotrhlin byla využita metoda akustické emise. Toto měření bylo doplněno analýzou změn zatěžovací frekvence zkušebního zařízení. Jsou ukázány a detailněji popsány další parametry signálu AE, získané s pomocí nově vyvinutého analyzátoru IPL s kontinuálním záznamem a zpracováním signálu AE.

Představeny jsou také nové postupy mechanického uchycení snímačů AE používané při únavových zkouškách na rezonančních strojích. Díky možnosti umístění snímačů AE v těsné blízkosti oblasti předpokládaného vzniku trhliny bylo pozorováno významné zlepšení kvality snímání AE dat v průběhu únavových zkoušek.

1 INTRODUCTION

Al alloys present a very important group of construction materials, which are used because of their specific properties in many industrial applications, especially in the area of transport engineering. Products made of these materials must satisfy high requirements during long time periods. A considerable problem of Al alloys (whose semi-products are fabricated by forcing-through method) is non-homogeneity of structure [1], [2]. This non-homogeneity can influence some mechanical properties and consequently the properties of individual real parts can differ.

The fatigue process of materials can be usually divided into different stages: changes of mechanical properties, beginning and rise of the first micro-cracks, propagation of short cracks, macros-

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copic spread of cracks and final fracture. Any plastic deformation causes changes in the material structure and they lead to the changes of some material properties.

With cyclic charging, it is possible, the hardening can occur during from the first cycles up to - the condition of saturation. Furthermore the properties do not change. The cyclic deformation occurs with a slip – after the initial hardening (softening), the deformation becomes concentrated to persistent slip bands (PSB). For the first phase of the damage, it is to take the burst of cracks. However, to fix this moment is very very difficult. Arising of this mechanism has been described by a couple of authors, but their ideas are mostly based on the ideas of surface unevenness (extrusion and intrusion) resulting from accumulation of macroscopic sliding. These micro-cracks arise on the material surface mostly due to the fatigue charge namely in points where the local amplitude of plastic deformation reaches the critical value [3]. A fatigue micro-crack in aluminium material can arise by different mechanisms, e.g.

- In the persistent slip bands i.e. in the places where the cyclic plastic deformation is localized;
- On the grain boundaries;
- On inclusions of foreign phase (on the cracked inclusion or on the damaged boundary between inclusion and matrix in the sliding zone spreading from the violated inclusion);

Numerous factors (e.g. the grain size, kind of precipitates and inter-metallic phases, precipitate-free zones and the final texture of the surface) have influence on rise and development of these fatigue slip bands.

After a certain number of cycles the short cracks go joining stepwise resulting in one main (long) and it broadensand causes a cross- section decrease and the final fracture [4], [5], [6]. In our case (i. e. flat test samples) passes through the whole thickness and grows to the width.

One sphere of non-destructive testing tries to follow and describe the changes passing in material during the fatigue degradation. The Faculty of Mechanical Engineering (FME) of Brno University of Technology (BUT) provides the measurements of acoustic emission signals and respective technology. The method is based on sensing the elastic waves arising as a result of dynamic processes in the material charged with internal or external loading. This method is well featured with its high sensitivity as well as the possibility to detect only active defects in the whole tested sample.

After 40 years of its successful development, the acoustic emission method has many various applications. These do not cover only checking the conditions of constructions, pressure vessels, the monitoring the leaks from technological complexes and localisation of internal defects. It concerns also the domain of basic research in evaluation of physical processes inside the material. However, the last named domain does not have enough results concerning structural changes or degradation processes inside material during the fatigue charge, as the present research analysis shows.

In the Laboratory of fatigue properties of the Institute of machine and industrial design at FME, we provide acoustic emission signal measurements during the fatigue testing mainly in aluminium alloys. We are able to register the resonance frequency of tested sample to decipher the structural changes of material (the phase of cyclic reinforcement, of rising the first micro-cracks and the beginning growth of the main crack). The acoustic emission signal can also bring the attention to the processes delivering great elastic energies when the charging frequency does not show any visible changes (structural changes like regrouping the dislocation etc) [7], [8]. We have got also new knowledge regarding the detection of start and development of slip fatigue bandes (in hardened aluminium alloys) resulting of non-destructive follow-up with X-ray diffraction topography [9].

The main aim of this article is the description of processes going on in material during the material degradation namely with regard to the domain of initiation and propagation of main crack and this by means of additional parameters of AE signal. Another aim was to verify the function of a new mechanical grip for AE sensors. Its realisation has been supported by Science fund of the FME of Brno University of Technology.

2 EXPERIMENTAL PART

2.1 Material and experimental apparatus

The test samples have been made from the precipitation-way hardenable wrought aluminium alloy EN AW-2017/T4. Its chemical composition is mentioned in the Table No.1.

Tab. 1: Chemical composition of used Al alloy (wt %)

material / *element*	Si	Fe	Cu	Mn	Mg	Ni	Zn	Al
EN AW-2017/T4	0,7	0,7	4,1	0,5	0,6	0,1	0,3	Rest

The geometry and dimensions of the samples for fatigue tests are shown on Fig. 1. The fatigue tests have been made on the testing electro-resonance pulsator RUMUL Cracktronic 8204/160 under the condition of 4-point bending. The equipment works under the sample resonance frequency depending on the sample rigidity. Basic parts of this equipment able to work with a maximum moment 160 Nm are shown on Fig. 2. The resonance frequency of the above mentioned samples moved around the value of 70 Hz under the bending tension 210 MPa.

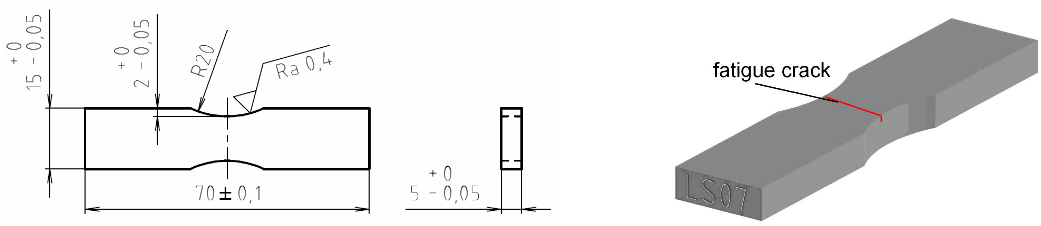


Fig. 1 Specimen geometry used for the fatigue tests

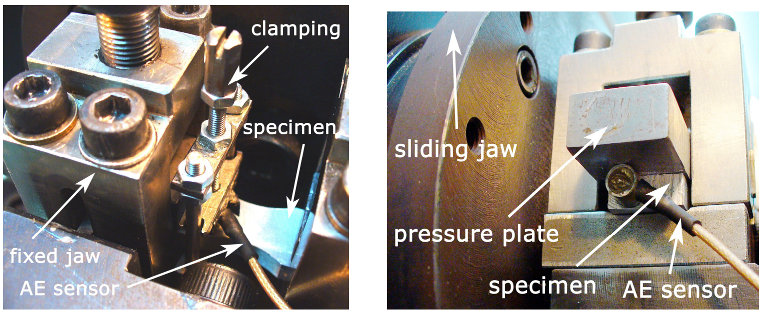


Fig. 2 Basic parts of the Cracktronic 8204/160 machine

Two acoustic emission piezo-electric sensors made by company Dakel, type MIDI, with diameter 6 mm, were used during for detection of acoustic emission waves during the fatigue charge. One has been placed in the neighbour of the notch by means of the mechanical grid (see Fig. 2 left) and the other one glutted to the front part of the sample (see Fig. 2 right). Signal from the AE sensors have been amplified with preamplifier and so modified lead to be evaluated in the measuring system Dakel-Xedo and IPL by cable trace.

2.2 Configuration of the experimental tests

The AE signal has been evaluated with 2 measuring systems: Dakel Xedo and Dakel IPL. **Dakel Xedo** analyser is a multi-channel system for the analysis of acoustic emission signals making possible the sampling and saving of measured values to the disk of steering Personal Computer. The analyser covers the frequency scope approximately 80 – 550 kHz. The analyser **Dakel IPL** makes moreover possible the continuous sampling and saving the whole signal up to the completing data memory of the disk. It registers also even overshoots for tuned levels as well as information on events. It gives the possibility to make three-dimensional recordings showing the time (horizontal line) / frequency (vertical axe) recording (see Fig. 9). The third parameter is the colour scale showing the density corresponding to frequency in all three registered acoustic emission events.

The acoustic emission signal has been measured up to the fracture. The main intention was to register the activity of acoustic emission signal in the time shortly before arising and growing main fatigue crack. All measurements have been completed with registrations of resonance frequency changes for the tested sample taken with the fatigue charge equipment RUMUL Cracktronic. The acoustic emission sensor and both analysers have been calibrated by means of Pen-test (Hsu-Nielsen source) with graphite 0,5 mm.

Before the acoustic emission signal became to be measured, the newly developed mechanical grid (see Fig. 3) had to be fixed to the sample and then the acoustic emission sensor positioned there. The measuring system has been configured with help of the Daemon software from the same Dakel company. It concerned strengthening the input amplifier, setting-up the memory oscilloscope parameters (like sampling speed etc) and the parameters of emission event.

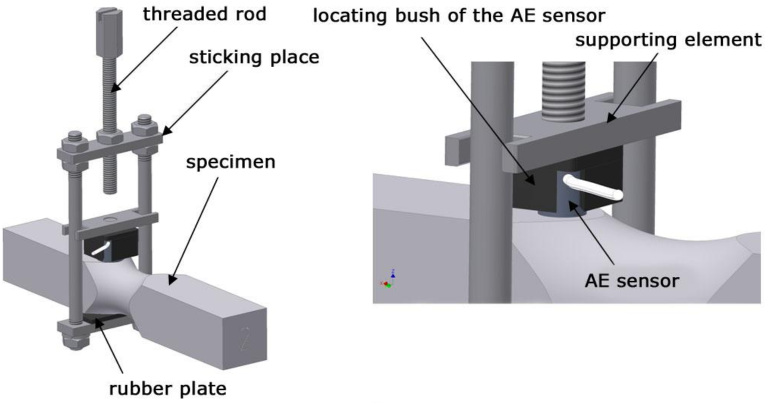


Fig. 3 Basic parts of the mechanical clamping (with other type of specimen)

During the acoustic emission signal measurements with the system Dakel-Xedo, the followed parameters have been the following ones:

- RMS – the mean quadratic level of the signal tension;
- Counts – number of acoustic emission signal shoots over the threshold level;
- Signal frequency spectre – power spectral density (PSD).

The following parameters have mainly been followed with the individual emission events:

- Rise time – the time from the first step over the threshold up to emission event peak amplitude;
- Peak amplitude of the emission event;
- Duration of the peak emission event;
- Duration of the emission event;

3 RESULTS OF AE SIGNAL MEASUREMENT

3.1 Dakel - Xedo

A sample of the acoustic emission signal registration namely of the whole fatigue testing the aluminium alloy EN AW-2017/T4 in the direction TL with the bending tension 210 MPa is found on the Fig. 4. This record comes from the acoustic emission sensor placed near the notch. We can notice an important growth of the emission activity between 14th and 18th and 26th and 34th minutes. It can mean material changes of the microstructures (movement of the fatigue slip zones, movement and regrouping of dislocations as well as other ones). The observations by means of X-ray diffraction try to answer the question what kind of changes are erasing as result of cyclic charge as mentioned in he introduction. It is however not the main topic of this contribution.

The beginning of main crack propagation is visible in the second half of registration (from 43 minute) in the higher emission activity of individual counts as well as on the RMS parameter. The development of the sample charging (resonance) frequency as registered by the equipment Clacktronic helps us to describe more plausibly these processes. We are able, for example, to determine the beginning of min cracks existence as it becomes noticeable due to visible falling the resonance frequency (on the Fig. 4 it makes about 160 000 cycles).

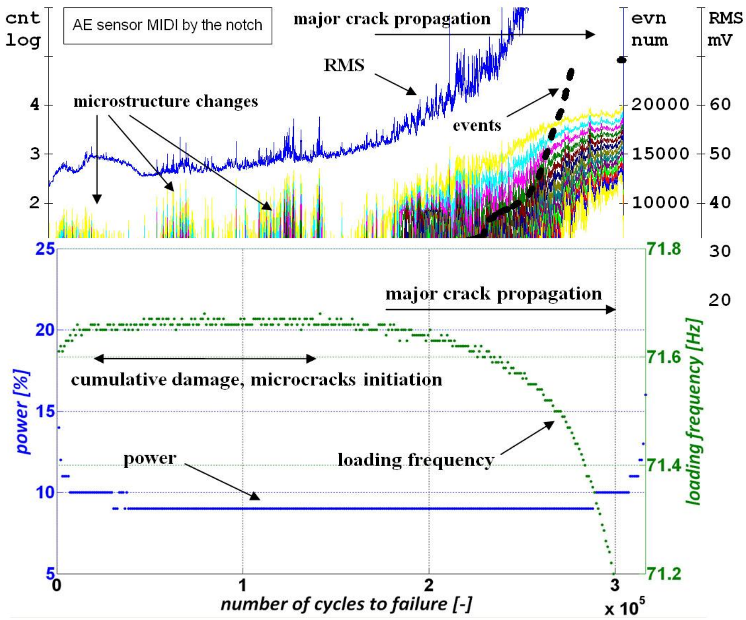


Fig. 4 AE signal - counts rate, RMS voltages, cumulative AE events (up) and plot of loading frequency changes (down) from fatigue test of aluminium alloy EN AW-2017/T4

Basic parameters of AE events (like rise time, emission event peak amplitude and emission event duration) as reached by the same examination are shown on the Fig. 5. In the upper part of the plot, we can notice the time interval around 1000th second where the values of maximum signal amplitude become dissipated from 600 mV up to 2400 mV. Similar phenomenon we can observe also between 1800th and 2100th second. There, the values of rise time parameter concentrated in an area become separated to another smaller area around 250 microseconds (green triangles in the diagram). This is the description of parameter changes prior to rise of main crack and begin of its propagation. It usually happens around 2500th second by grooving the maximum amplitude signal as well as further rise of separated “islands” of the rise time parameter (750 or 1700 µs).

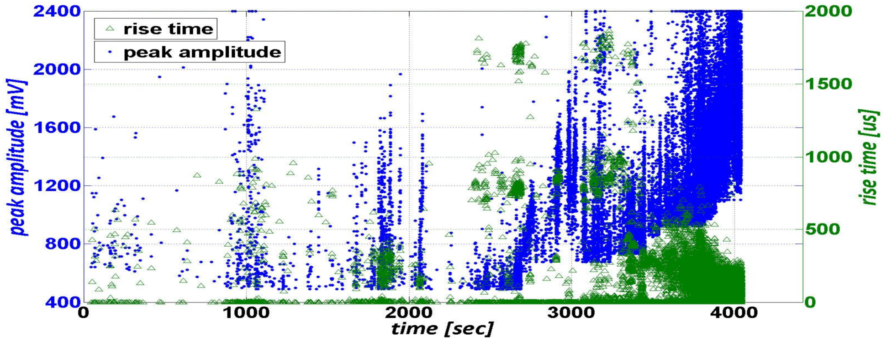


Fig. 5 Basic parameters of AE events (peak amplitude, rise time, event duration) from fatigue test of aluminium alloy EN AW-2017/T4

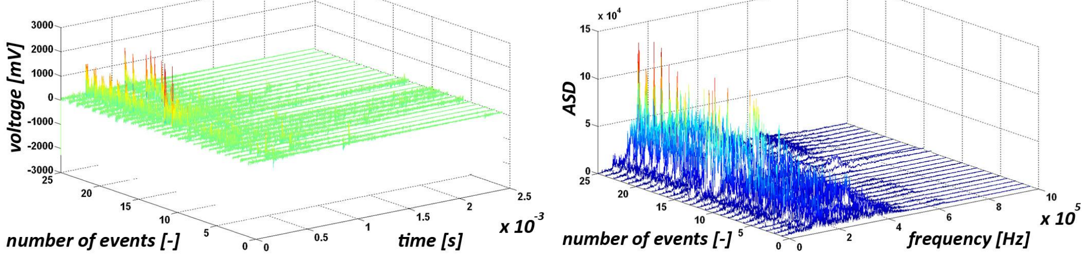


Fig. 6 a) exemple of AE events record (app. from 35-45 minutes of the test or 1,5–1,9.10^5 cycles, see Fig. 4 – the period, when happens to start of diffusion of main fatigue crack),
b) amplitude spectrum of AE signal from Fig. a (maxima about 160 kHz).

The changes working inside the material during the fatigue charge like rise of micro-cracks, movement of dislocations and first of all the beginning of main crack propagation can be described following the above mentioned changes of AE event parameters. However, the real changes in the material have not been identified in the base of the above parameters.

The scope of values measured with regard to parameter of acoustic emission events as observed:

- rise time (μs): 0 ÷ 1800
- signal maximum amplitude (mV): 500 ÷ 2400
- event duration (μs): 1100 ÷ 2800

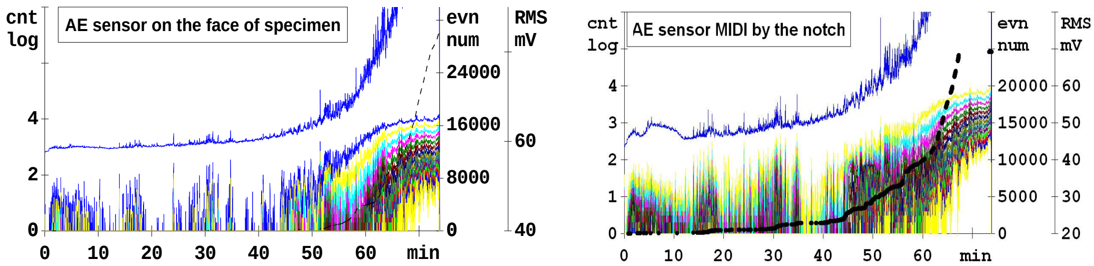
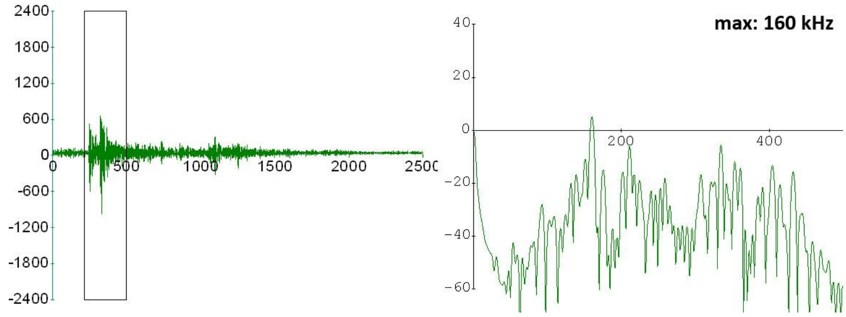


Fig. 7 Record of the AE signal (counts rate, RMS voltages, cumulative AE events) from fatigue test of aluminium alloy EN AW-2017/T4, a) AE sensor on the face of specimen,
b) AE sensor by the notch.

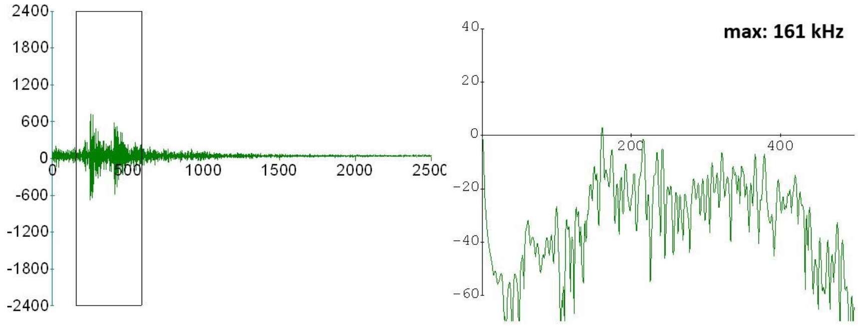
AE signal courses for both sensors used for the same test are shown to give a complete picture on Fig. 7. Conditions and settings are the same. The record of data gathered from the sensor glutted to the sample frontal part is on the Fig. 7a and the other one from the neighbour of the notch and taken with new type of sensor grid is on the Fig. 7b. Both records show clearly, the signal coming from the sensor on the sample front is not so sensitive to small changes in the micro-structure with regard to the sensitivity of sensor near to the notch. The difference can be followed on the RMS parameter as well as in the number of active levels (counts). The shape of the AE signal however remains not changed.

Fig. 8 shows the typical acoustic emission signal events in different moments of the examination as they are presented in both time and frequency scales.

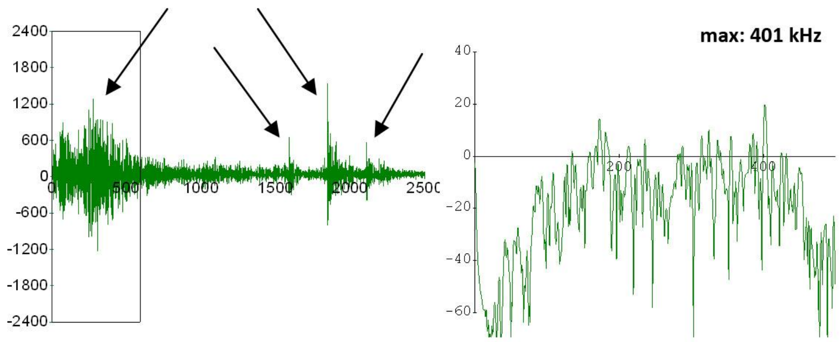
The short time one-shot increments are not violent during the first minutes of the examination and the extreme value transmitting the biggest part of signal power (in the frequency part) moved around 160 kHz (see fig. 8a). The features of events (in time as well as in frequency domain) did not change too in the interval of micro-crack occurrence i.e. in the phase of microscopic slid accumulation (as well in time and frequency domain). See Fig. 8b. These short time impulses (repeated even five times during one event) grew and maximum frequency shifted to the value of 400 kHz as late as the main crack has come into existence followed by its broadening. See Fig.8c. The signal transformation from the time into the frequency domain has been provided with the window „Hanning“.



a) after 20 minutes (at 14:44, cumulative damage)



b) after 31 minutes (at 14:54, major crack initiation)



c) after 63 minutes (at 15:28, major crack propagation/fatigue failure)

Fig. 8 Selected AE events in the different times (AE sensor by the notch)
start of fatigue test: 16. 4. 2010, 14:24 end of fatigue test: 16. 4. 2010, 15:38

3.2 Dakel - IPL

Also, the acoustic emission signal activity has been also measured during the fatigue tests of the aluminium alloy EN AW-2017/T4 with analyser Dakel – IPL, developed newly. The main feature of this analyser is the continuous sensing of acoustic emission signal frequency zones during the whole time of the examination (in this case it was around 83 minutes). Fig. 8 shows then the results of fatigue testing under bending stress 210 MPa. It concerns one test with acoustic emission signal sensed by two acoustic emission sensors.

This shows the records of the sample resonance frequency course received with charging equipment RUMUL, further the records of the time / frequency spectre and finally he scan of frequency domain in any test moment chosen. The last diagram can be imagined as longitudinal cross-sections of time / frequency spectre. It is also possible to get the transversal cross-sections and to show this way the signal frequency spectre in any test moment.

The frequency spectre / time record does not change too much on the Fig. 8a and it moves around 130 to 250 kHz with sporadic shoots starting with 3600th second. From the sensor on the sample notch, it is possible to see another course (see Fig. 8b) where the frequency maximums moved in broader dissipation area namely from 130 up to 400 kHz. We can also notice the signal power has been a little bit transmitted in the higher frequency domains (650 kHz) mostly towards the test end.

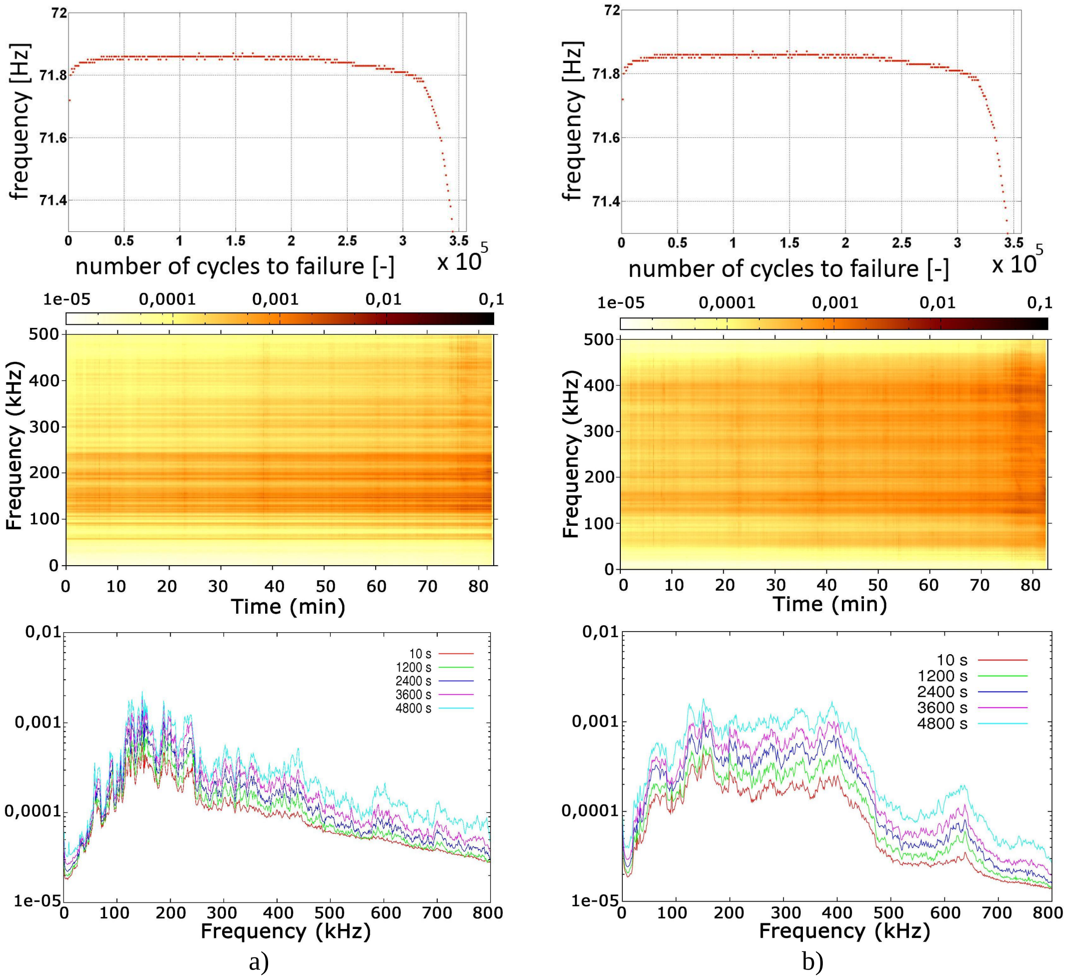


Fig. 9 Continuously sampled AE signal obtained by new analyser DAKEL IPL: a) AE sensor MIDI – pressure plate (channel 2; 10 dB), b) AE sensor MIDI – by the notch (channel 1; 10 dB)

4 CONCLUSIONS

Results of the acoustic emission signal treatment during the fatigue charge of the aluminium alloy EN AW-2017/T4 indicate that the application of this non-destructive testing method is an important contribution to the basic research of fatigue processes in the material. The acoustic emission method has identified (by means of Dakel-Xedo analyser) the changes passing in the material, namely the process of defects accumulation and starting growth of main crack. Also the detailed data concerning the changing AE signal parameters (like rise time, signal maximum amplitude etc.) present also important information. However, we did not find yet a relevant correlation between these parameters and changes passing inside the material during the fatigue damage. The results of acoustic emission signal measurements on the Dakel – IPL analyser present another chapter if this research. This analyser makes possible to sample and save continuously the acoustic emission full signal. And this measuring system allowed also to have made a more detailed analysis of frequency spectre during the whole testing time. The records from Dakel – IPL and Dakel-Xedo then could be compared. It is however necessary to analyse more minutely the parameters of acoustic emission signals from both systems (i.e. Dakel – IPL and Dakel – Xedo) in framework of the further research of the acoustic emission method during the fatigue test. These parameters could describe the changes in the microstructure of the materials studied.

Also the records of the resonance frequency sample received with the charging equipment RUMUL Cracktronic appeared as a contribution to the research. They have given us more complex information concerning the material fatigue degradation passage. Moreover, we have done the experiments with the grid newly developed. Il serves to fix the acoustic emission sensors on the test samples because the old method using glue was not reliable and caused frequently the damages to the sensors. The fixing of sensors by means of the newly developed clamps is safe. Moreover the new clamping system makes possible to position the acoustic emission sensors nearer to the sample notch and the conditions for signal take-up are much better.

Works, the results of which are presented in this paper have been carried out in the framework of the project of a Science Fund of FME nr. BD 139 3006 – "*System of acoustic emission sensors clamping parts for fatigue tests of nonferrous alloys*" and of the project of MSMT CR nr. 1M2560471601 *„Ekocenter of applied research of nonferrous metals" - workplace Brno.*

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