ACOUSTIC EMISSION MONITORING OF COMPOSITE WING FATIGUE TEST

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Abstract. Fatigue tests of two identical composite wing specimens were performed. The goal was to identify and localize acoustic emission events and thus monitor the process of structural degradation of wing specimen during the fatigue test. First test covered 12 000 flight hours (two fatigue lives) and was stopped without any obvious damage. Second test covered 60 576 cycles when the structural failure occurred in the bonded joint. Acoustic emission was measured by DAKEL-XEDO-3 system, which is designated to measurement and evaluation of AE, localization of AE sources and recording of emission signal. The acoustic anisotropy was detected in both tested segments. Significant amount of acoustic emission events was observed when the amplitude of the loading force was crossing the zero value. This is not connected with the segment structural degradation. Sources of these events were mainly in fixing jig friction joints. Cluster analysis was used for better identification of localized sources and for better specification of their location. AE evaluation confirmed a significant AE activity growth in the last 27 minutes of the second test. Localization of these sources agrees with actual failure location.

Keywords. Fatigue test, acoustic emission, composite, wing.

1 Introduction

This paper presents the results of composite wing fatigue test monitoring by the acoustic emission (AE) method. Fatigue tests of two identical composite wing specimens were performed at the Institute of Aerospace Engineering in Brno University of Technology during September 2007 and June 2008. The goal was to identify and localize acoustic emission events and thus monitor the process of structural degradation of wing segment specimen during the fatigue test.

2 Materials and methods

2.1 Specimens and cyclic loading

A root part of the wing is the most critical and the most stressed part of an airplane structure. Therefore, this part was selected to be a subject of fatigue tests with acoustic emission monitoring for better understanding of a structural behavior processes.

Tests were performed on a wing segment with one spar construction and sandwich skin from carbon/epoxy laminate. The wing spar was made from carbon/epoxy roving flanges and glass/epoxy laminate web. Root rib and spar cantilever were also parts of the tested segment. Basic specimen dimensions and test configuration are schematically shown on Figure 1.

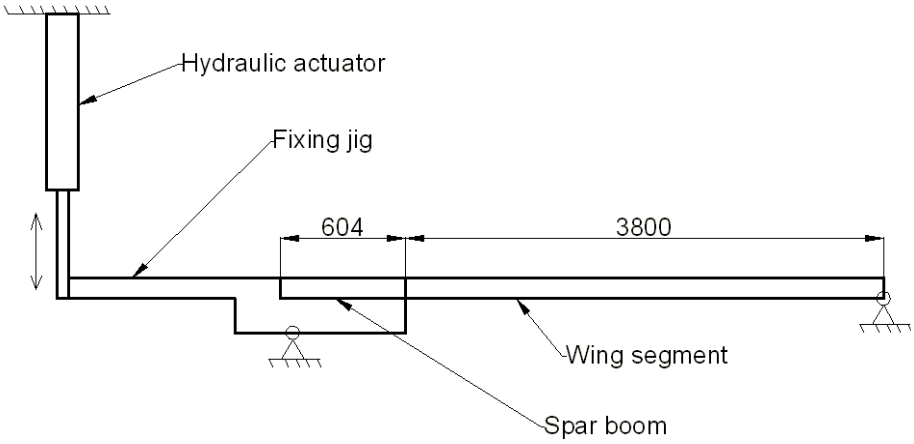

Figure 1: Specimen dimensions and test configuration.

The segment was loaded by a hydraulic actuator joined with the fixing jig. Load cell was also a part of the assembly.

First test specimen X-06 was subjected to stochastic loading spectrum outgoing from spectrum KoSMOS2, test covered 12 000 flight hours (two fatigue lives) and was stopped without any obvious damage. Second specimen X-07 was subjected to cyclic loading with constant amplitude up to the positive and negative limit loads. This test covered 60 576 cycles when the structural failure occurred in the flange – web bonded joint in the cantilever area.

2.2 Acoustic emission measurement

Acoustic emission is a phenomenon occurring in stressed materials, when energy released from microstructural changes spreads in a form of transient elastic waves. Construction monitoring with a wide net of AE sensors allows detecting places with higher acoustic activity – emission sources. From emission source parameters, it is possible to evaluate the state of material degradation. Suspicion on defect presence can be confirmed or disproved by application of other diagnostic methods, primary directed to the detected acoustic emission sources.

During repeated loading of the specimen without defect it is possible to observe Kaiser effect, which means that no acoustic emission activity is observed until the stress exceeds its previous high value [4, 5].

Acoustic emission was measured by DAKEL-XEDO-3 system that is designated to measurement and evaluation of AE, localization of AE sources and recording of emission signal. Measuring chain consisted of:

- 14 piezoelectric sensors of AE
- 14 preamplifiers
- measuring unit DAKEL-XEDO-3
- PC for evaluation and recording of the measured data

AE sensors were bonded on the skin of the wing segment. Their positions are apparent from Figure 2.

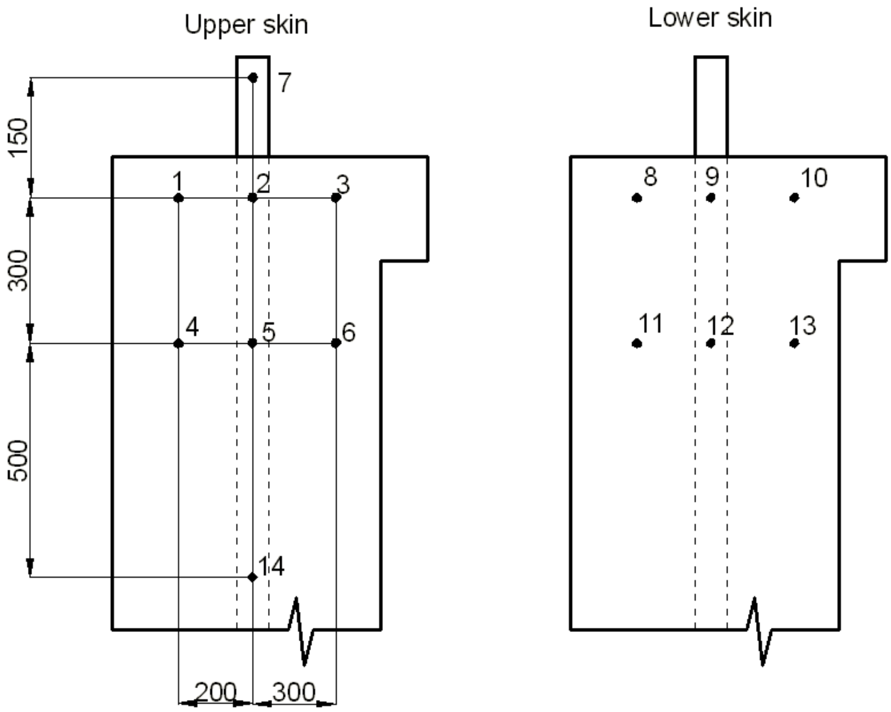

Figure 2: Location of AE sensors.

Next, the acoustic wave's velocities were measured in different directions and ability to localize AE source was confirmed by pen test (Hsu-Nielsen source according to [4]). Threshold crossing (Count1, Count2) and standard deviation RMS were monitored during the fatigue test. Evaluation included localization of AE sources and AE sources occurrence monitoring in the terms of loading force behavior.

For the X-07 specimen the same measuring methods were used including identical sensors placement.

3 Results

The acoustic anisotropy was detected in both tested segments. The biggest velocity (8720 m/s) of acoustic waves was in the direction of the carbon wing spar between sensors 5 and 14. The lowest velocity (2308 m/s) was observed in the direction perpendicular to the wing axis between sensors 9 and 10.

3.1 Specimen X-06

After initiation of the fatigue test, the acoustic emission was detectable only with higher amplitude of loading force then the highest amplitude applied before. This is known as already mentioned Kaiser effect.

Significant amount of acoustic emission events was observed when the loading force was approximately zero. This is not connected with the segment structural degradation. Sources of these events were mainly in fixing jig friction joints.

During next progression of the fatigue test the significant growth of precisely localized AE events were observed. This was considerably high in region C, as can be seen from Figure 3.

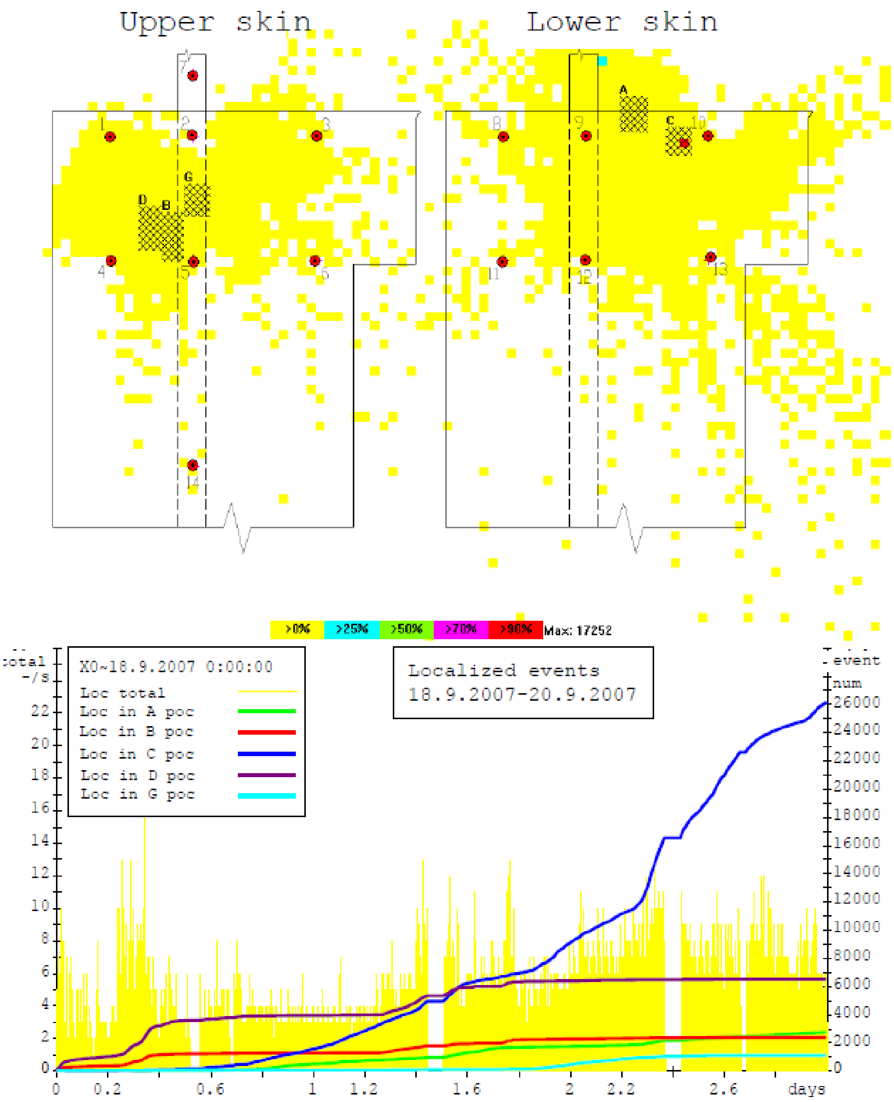

Figure 3: Localized events.

These events were at the descending part of the loading cycle right before zero amplitude. Similar phenomenon was observed during fatigue tests of laminated wind turbine blades tested by Texas University [4]. Events at small levels of loading are not considered in the evaluation of AE [4]. For next evaluation the filtration of localized events was done in relation to the loading force. There were no events observed in region C outside interval (-0,5 kN; 9 kN).

In next progression, the AE sources were relocating in observed area of the wing segment. Acoustic emission from each source was characterized by increase and following decrease.

3.2 Specimen X-07

Filtration of AE events was done for loading force <-10 kN and >25 kN. Detected emission sources were not significant and were observed in starting and middle phase of the test. And thus these sources were not related to the wing segment destruction. Figure 4 presents the localization map for upper and lower skin for last 27 minutes before specimen X-07 destruction. Filtration is done for loading force >25 kN. There is a significant emission source between sensors 9 and 12 on the lower skin. Location of this source is well connected with location of spar collapse.

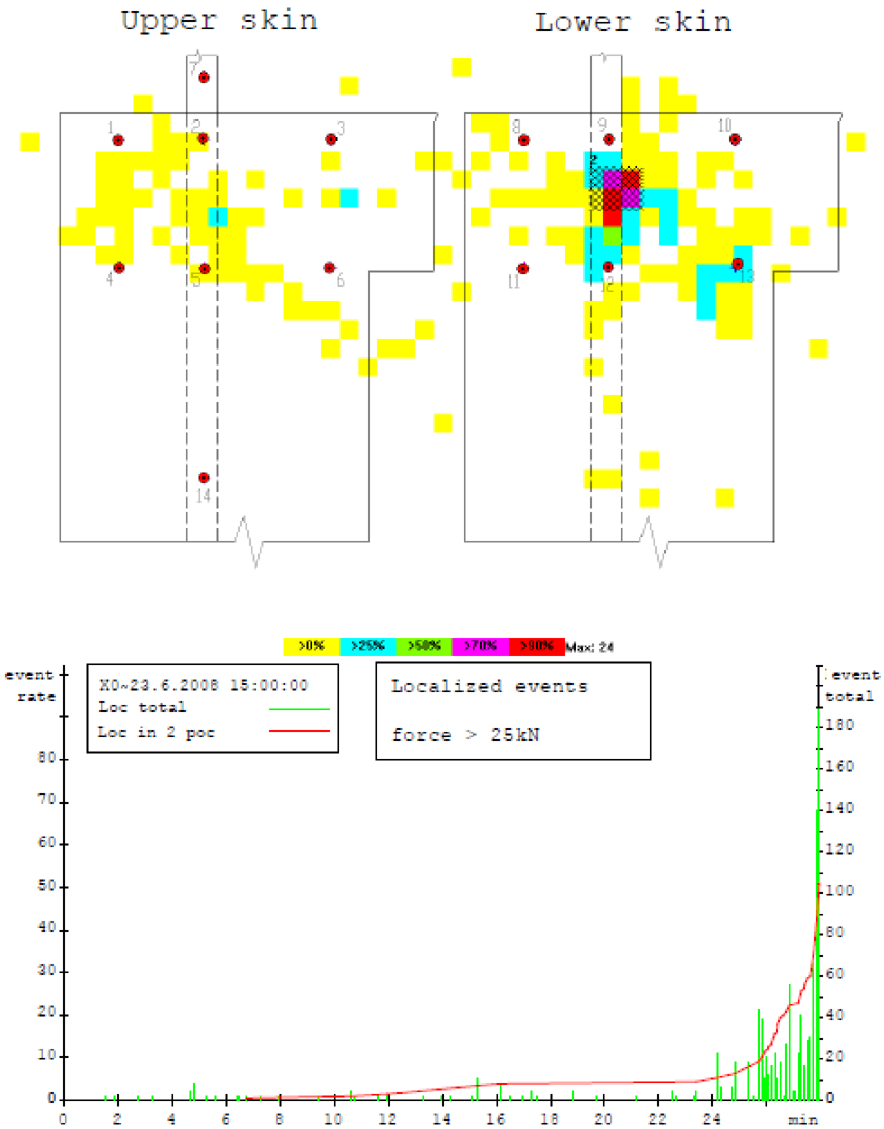

Figure 4: Localized events for last 27 minutes.

Cluster analysis was used for better identification of localized sources and for better specification of their location. Set of AE sources parameters from sensor 9 was used as a basis because of its closest location to the actual structural break of the wing segment. Sorting of events from this sensor was done according to similarity of following parameters: event duration (length), maximum amplitude rise time (rise) and maximum amplitude (max). Majority (90%) of acoustic events was characterized by parameters: length<700 μs, rise<200 μs a max<1300 mV. The rest 10% were marked as outliners and excluded from further analysis. Expectation maximization algorithm provided six clusters sorting. Cluster analysis result is in Figure 5. Further analysis showed that acoustic events from clusters 0, 1, 2 are linked with spar connection to the fixing jig when localization was performed for all the data without filtration. This connection is most acoustically active during zero loading points. Acoustic events from clusters 0, 1, 2, 3 and 5 were connected with the location of the spar structural damage when localization was performed for the data filtrated for loading force >25 kN.

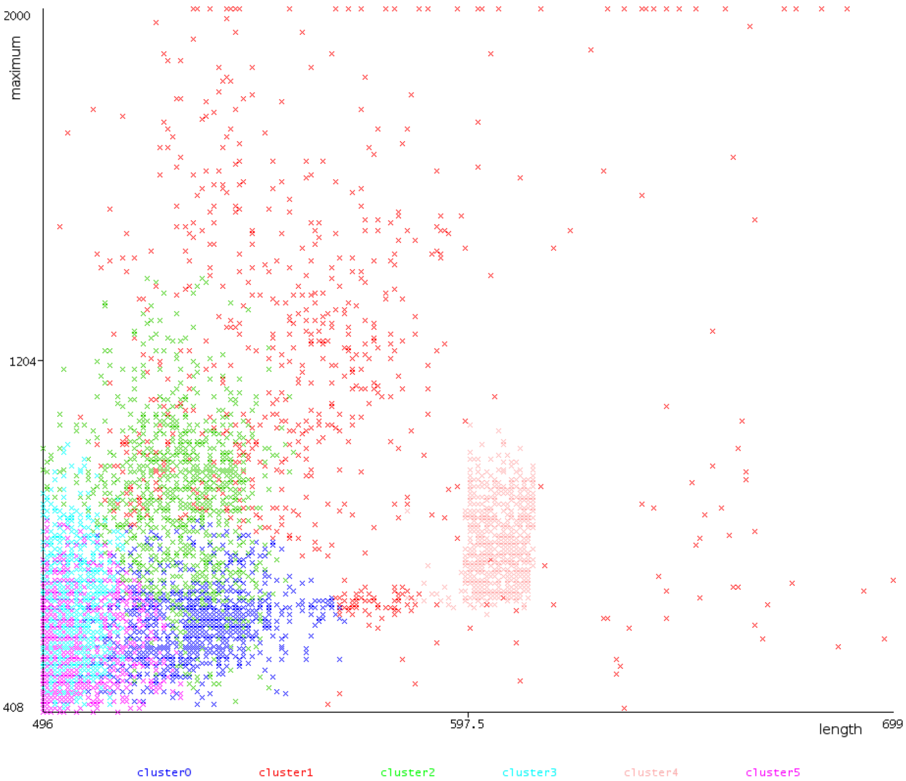

Figure 5: Cluster analysis results.

When every detected acoustic event has a loading force magnitude assigned in a time of its detection, we obtain zones with higher concentration of AE events (see Figure 6).

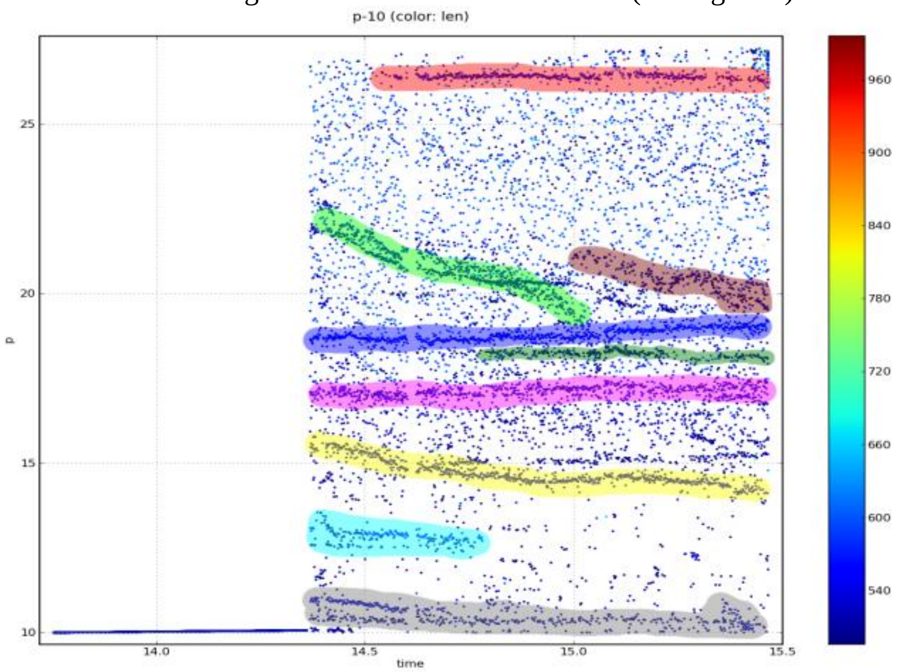

Figure 6: Sensor 9 AE event time vs. related force.

Localization of these events showed that red zone is linked with the spar destruction while green, blue and dark green zones are linked with fixing jig connection to the wing segment.

Next, all measured data were analyzed in this manner (see Figure 7). Zones with higher emission activity in this figure have decreasing tendency and after certain time they disappear. This is explained by theory that deformation process causing AE event in certain location is redistributed to another location until it disappears completely and then acoustic emission source is localized elsewhere.

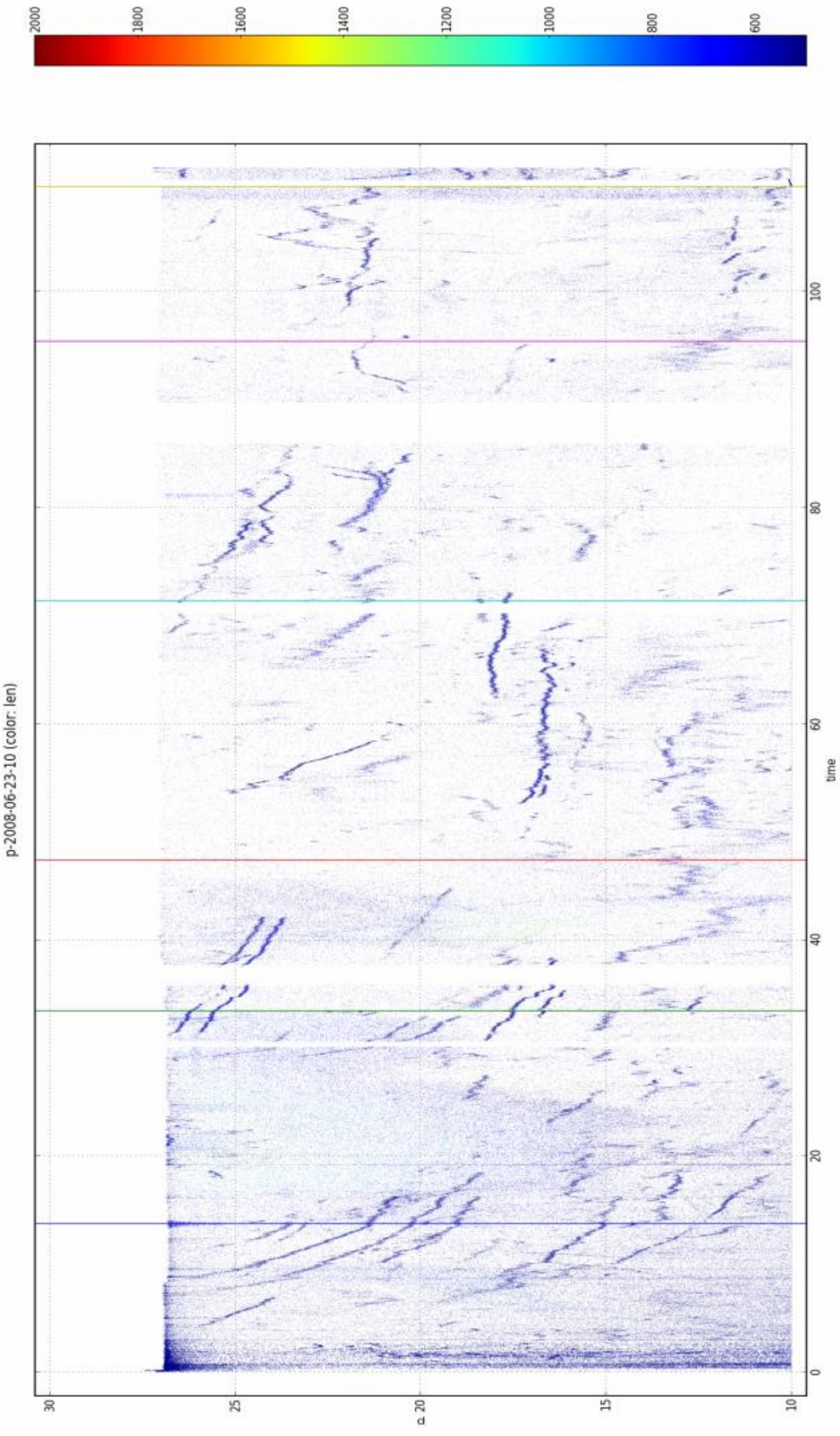

Figure 7: Sensor 9 AE event time vs. related force.

4 Discussion

Acoustic anisotropy was confirmed in both tests. In the initial faze the Kaiser effect was observed. During the test of X-06 specimen, no structural damage development was observed. Specimen X-07 was subjected to more aggressive loading spectrum and structural failure occurred after 60 576 cycles. AE evaluation confirmed a significant AE activity growth in the last 27 minutes of the test. Localization of these sources agrees with actual failure location.

Elimination of emission sources that are not connected with the structural degradation is possible by cluster analysis.

Degradation processes are occurring in certain location of the specimen during the fatigue test. This is exhibited by localized AE sources, which after stress (or strain) redistribution gradually vanish and they are localized elsewhere after that. This hypothesis is confirmed by correlation of loading force versus time of localized event, which is graphically demonstrated by higher emission activity bends with decreasing tendency (see Figure 7).

5 Conclusion

AE evaluation is complicated and time consuming because of large amount of collected data. For source localization, it is necessary to use a filtration with regard to loading force. Many AE events are appearing during the zero loading force and thus they are not connected with structural degradation process and must be excluded from the analysis. On the other hand, AE events corresponding to maximum loads confirm to have a significant structural degradation effect. It was also possible to localize the place of structural failure by standard linear localization method in spite of detected material acoustic anisotropy.

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