

# PROPORTIONAL MONITORING OF THE ACOUSTIC EMISSION IN CRYPTO-CONDITIONS

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## Abstract

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The work is aimed at studying corrosion and fatigue properties of aluminum alloys by means of acoustic emission (AE). During material degradation are acoustic events scanned and evaluated. The main objective of the article is a description of behavior of aluminum alloys degraded in specific conditions and critical degradation stages determination. The first part of the article describes controlled degradation of the material in the crypto-conditions. The acoustic emission method is used for process analyzing. This part contains the AE signals assessment and comparing aluminium alloy to steel. Then the specimens are loaded on high-cyclic loading apparatus for fatigue life monitoring. Also, the synergy of fatigue and corrosion processes is taken into account.

The aim is the description of fatigue properties for aluminum alloys that have already been corrosion-degraded. Attention is also focused on the structure of fatigue cracks. The main part of the article is aimed at corrosion degradation of aluminium alloys researched in real time by means of AE. The most important benefit of AE detection/recording is that it provides information about the process in real time. Using this measurement system is possible to observe the current status of the machines/devices and to prevent serious accidents.

acoustic emission, AE, corrosion, aluminium alloys, degradation, crypto-conditions, mechanical loading, fatigue loading, fatigue crack

Nondestructive testing (NDT) is a wide group of analysis techniques used in science and industry to evaluate the properties of a material, component or system without causing damage (Hellier, 2003).

One of these methods is acoustic emission (AE). This inspection technique detects elastic waves generated within a test specimen by such mechanisms as corrosion, plastic deformation, fatigue, and fracture. It differs from ultrasonic inspection, which actively probes the structure; AE listens for emissions from active defects and is very sensitive to defect activity when a structure is loaded beyond its service load in a proof test. This process can detect flaws and imperfections such as the initiation and growth of fatigue cracks.

In this work, AE was used to study the corrosion process and the formation of cracks during cyclic loading. Corrosion is a slow, progressive or rapid deterioration of metal body properties such as

its appearance, surface aspect or mechanical properties under the influence of the surrounding environment: atmosphere, water, seawater, various solutions, organic environments, etc. (Vargel, 2004).

The specimens were degraded in accelerated corrosion conditions and monitored using the AE testing. By means of laboratory tests and data analysis it is possible to effectively predict behavior of materials in real operating conditions. This can increase the safety of machinery, equipment and processes. Also, it can prevent major accidents and upgrade processes.

The work deals with monitoring of fatigue life for aluminium alloy EN AW-7075 specimens degraded by corrosion. Fatigue is a progressive and localized structural damage that occurs when a material is subject to cyclic loading. The nominal maximum stress values are less than the ultimate tensile stress limit.

Fatigue occurs when a material is subjected to periodic loading and unloading. If the loads are above a certain threshold, microscopic cracks will begin to form at the surface. Eventually a crack reaches a critical size, and the structure suddenly brakes. In this work, we paid attention to synergy effect of fatigue and corrosion processes. The destruction process was monitored by AE diagnostic method.

## MATERIAL AND METHODS

### Specimen material

An aluminium alloy EN AW-7075 was used as an experimental material. It is the hardened high strength alloy.

#### Chemical composition (%)

| Material                             | Si  | Fe   | Cu   | Mn   | Mg  | Cr   | Zn   | Al   |
|--------------------------------------|-----|------|------|------|-----|------|------|------|
| AlZn <sub>6</sub> Mg <sub>2</sub> Cu | min |      | 1.4  | 0.20 | 1.8 | 0.10 | 5.0  | rest |
|                                      | max | 0.50 | 0.50 | 2.0  | 0.6 | 2.8  | 0.25 | 7.0  |

### AE Diagnostic System

The DAKEL - XEDO diagnostic system is an advanced device for capturing and recording of AE parameters, localization of AE sources, and signal sampling. Its main purpose is to monitor periodical pressure tests to detect any potential hidden defects in primary circuit technology material and to identify locations that have the highest probability of material defect occurrence. These locations can be then subject to more detailed examinations by other diagnostic methods. System sensors are permanently located on power plant primary circuit loops, in throat segment of reactor pressure vessel, volume compensator and pipeline network. Systems sensors can also act as electronic

transmitters (pulsers) enabling the function check and calibration of sensors.

### Corrosion Degradation

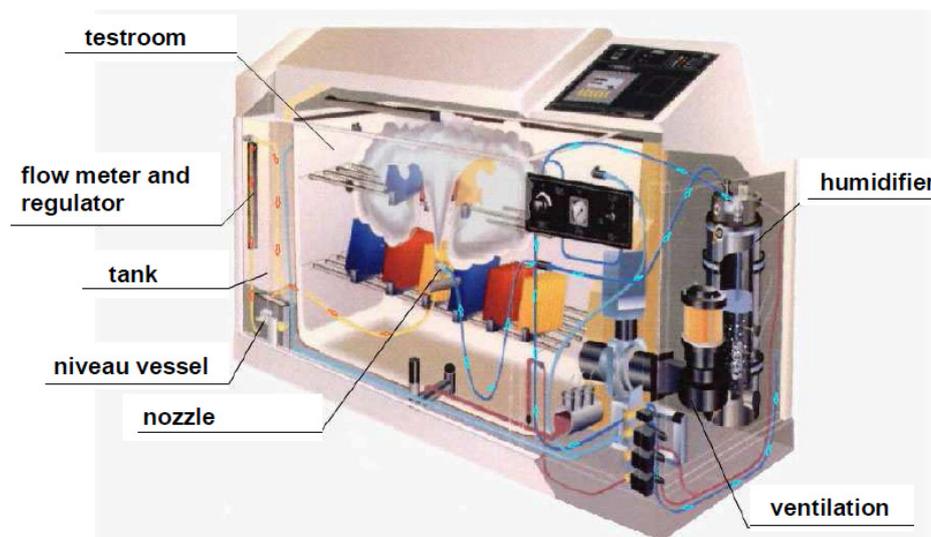
For the corrosion degradation, equipment made by the Liebisch Company was used. Figure 1 shows a salt chamber for accelerated corrosion process. Accelerated corrosion test was carried out according ISO 9227 standard. The test was performed in a corrosive environment in the form of salt fog (atmosphere of NaCl) in concentration of  $50 \pm 5$  g/l of distilled water. The density of the solution at this concentration and temperature of 25°C is 1.0225 to 1.0400 g.cm<sup>-3</sup>. This test is usually used for metals and their alloys, metal coatings, and organic coatings on metal surfaces.

The acoustic emission was measured by two Dakel MIDI sensors mounted on etalons using rubber bands. One etalon was made from aluminium alloy EN-AW 7075 and the other from standard steel for reference purpose. Signals from both sensors were analyzed by Dakel XEDO AE 4.0 in 80–400 kHz frequency range. Measured dataset was stored on the hard drive of a standard PC. Table I shows configuration of the Dakel XEDO analyzer.

### Fatigue Degradation

The fatigue life was assessed on the specimens degraded by corrosion in salt chamber for 21 days. The speed and the stage of fatigue degradation were sensed by acoustic emission diagnostic system. The specimens degraded by corrosion were cyclically loaded by four point bend at the Rumul Cracktronic 160 high-cyclic pulsator and their behavior was analyzed using AE. Figure 2 shows the specimen mounted on testing equipment with AE sensor attached.

The loading frequency is determined by the specimen stiffness. This frequency changes due to



1: Liebisch salt chamber  
Source: www.liebisch.com

I: AE parameters used in the configuration of the Dakel – XEDO analyzer

Source: authors

| Parameter             | Setting             |
|-----------------------|---------------------|
| Gain of analyzer      | 50 dB               |
| Gain of pre-amplifier | 35 dB               |
| Count 1 Threshold     | 302 per mille range |
| Count 2 Threshold     | 600 per mille range |
| Sampling rate         | 2 MHz               |
| Sampling memory       | 1 000 words         |
| Pretriggerer          | 1 000 words         |
| Period                | 1 000 ms            |
| Count start           | 600 per mille range |
| Count finish          | 600 per mille range |
| Dead time             | 992 micro-second    |
| Minimum length        | 100 micro-second    |
| Trigger               | 600 per mille range |

stiffness of the specimen. The crack initiation and propagation can be detected by changes in loading frequency.

The objective of this part of research is the process stage assesment in which a fatigue crack rises. It is a degradation phase, which precedes the final fragmentation of the specimen, respectively component in real practice.

The AE method makes it possible to “hear” the micro-structural changes in the specimen. An accumulated elastic energy is released in certain localities of the material due to cyclic fatigue loading, such as the formation and crack propagation.

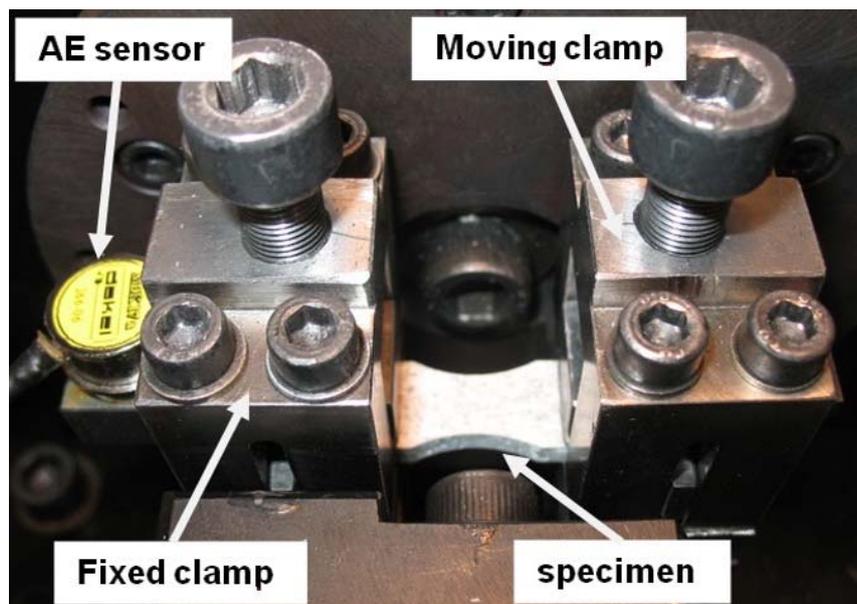
## RESULTS AND DISCUSSION

The experiment is divided into two closely related sections. In the first part, the corrosion degradation of aluminum alloys is evaluated. It was important to compare the aluminium alloy with standard machinery steel under severe corrosion conditions. The second part of the work deals with the evaluation of fatigue life of corrosion-degraded specimen.

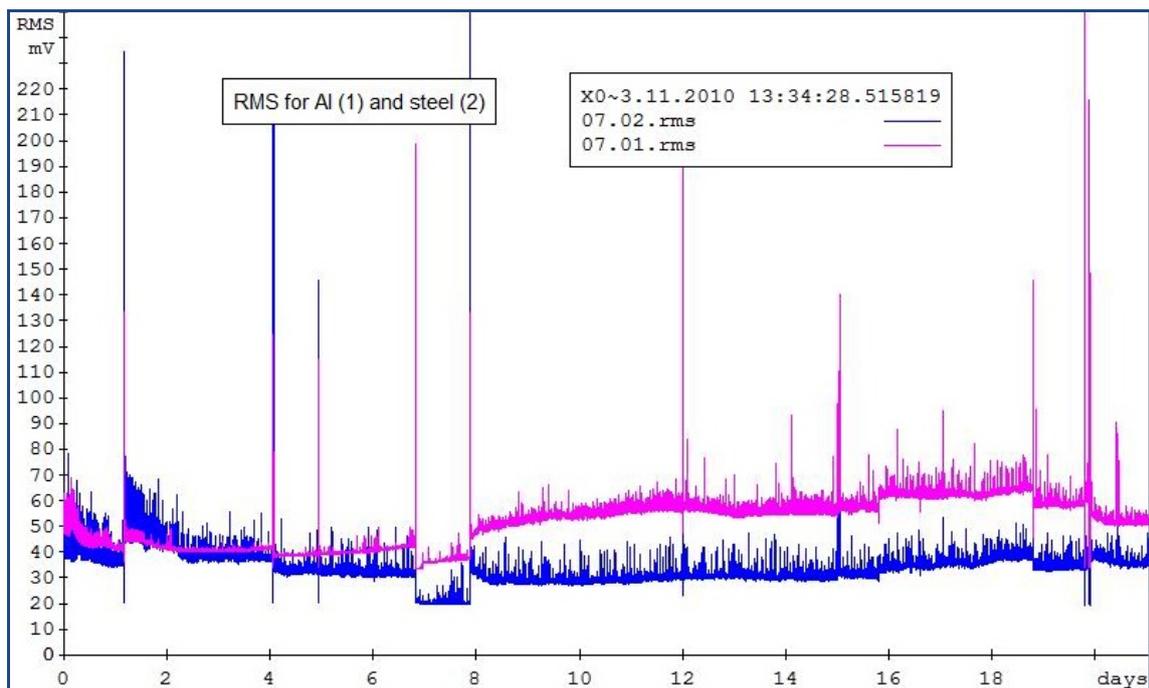
Root Mean Square (RMS) signal graph on Figure 3 shows the different activities of AE in aluminium alloy and steel. Measurement time (21 days) can be divided into several stages (A to D).

- *Phase A (day 1)*: both of etalons show approximately the same activity of AE with a slightly declining trend.
- *Phase B (day 2 to 4)*: AE activity at the steel etalon was higher than at the aluminum etalon. Steel etalon showed a significant increase in RMS values at the beginning of the second day of the experiment. Then, the RMS of steel etalon dropped to the level of the aluminum etalon at the end of the 4th day.
- *Phase C (day 5 to 8)*: AE activity in both etalons corresponded to relation of RMS AE Al > RMS AE steel. During the 8th day of the measurement, synchronous decreases of RMS signal for both etalons were registered.
- *Phase D (day 9 to 21)*: RMS AE signal at Al etalon was significantly higher (locally up to 60 mV over 40 mV in standard steel). This situation lasted until the end of the experiment.

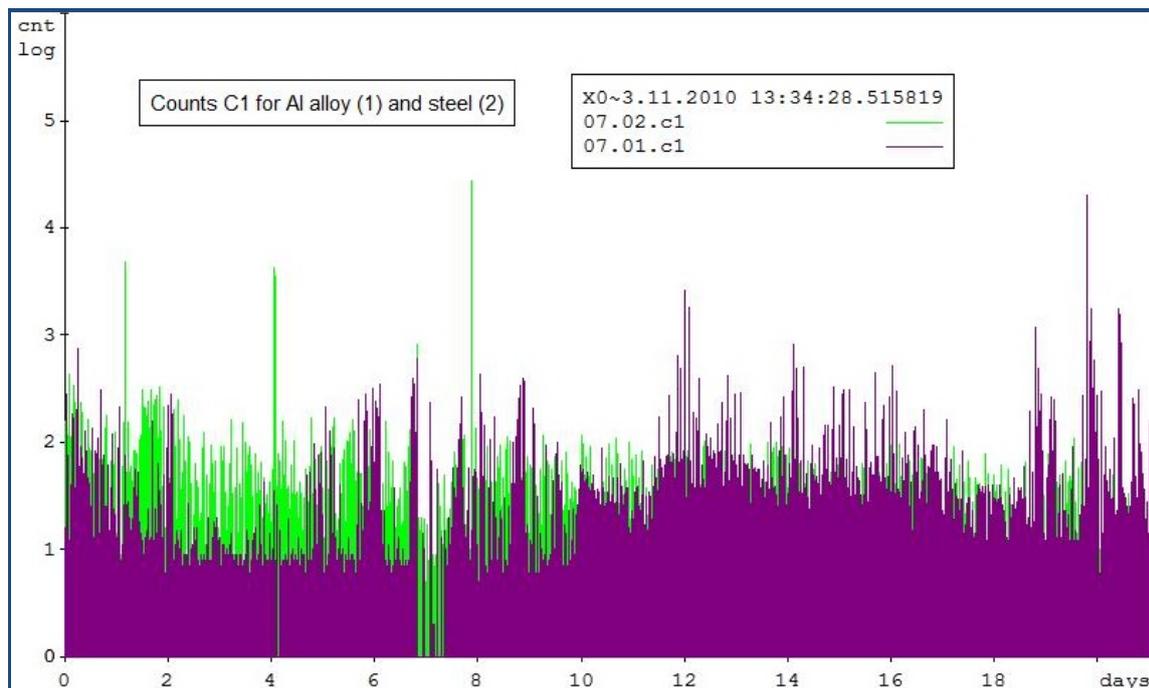
It is interesting to compare waveform parameters of Count 1 for both etalons (see graph in Figure 4). Clearly visible is the gradual trend of increasing superiority with Al alloy etalon (violet) over the steel etalon (green).



2: Rumul Cracktronic 160 with specimen and AE sensor  
Source: authors



3: RMS of AE signal from aluminium alloy and steel  
Source: authors

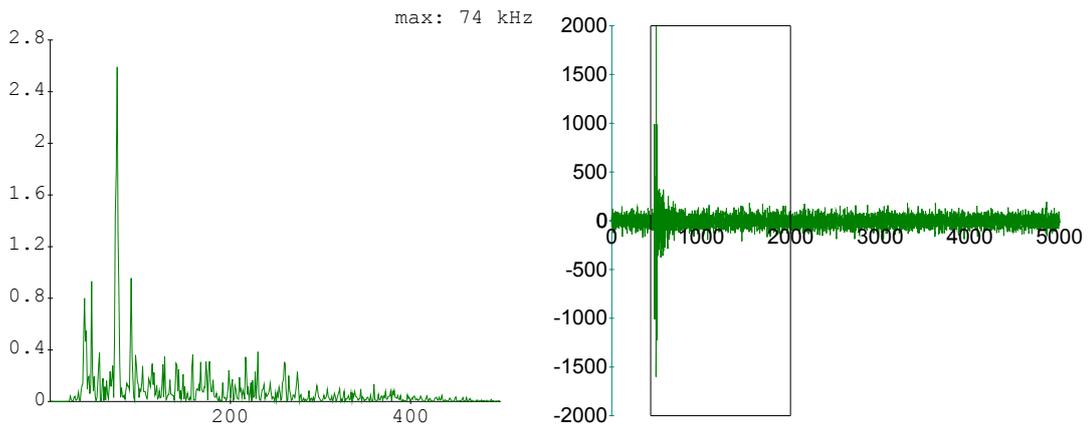


4: AE Counts C1 for aluminium alloy and steel  
Source: authors

The acoustic emission measured on aluminium does not correspond to that of the steel. Aluminium has a good corrosion resistance and it has status as one of the primary nonferrous metals by means of a barrier oxide film that is bonded strongly to its surface. This passive film, if damaged, forms again

immediately in most environments (Davis, 2003). This protective oxide layer creation was recorded using acoustic emission.

AE signals are sampled by means of XEDO system. Signals of both specimens were evaluated

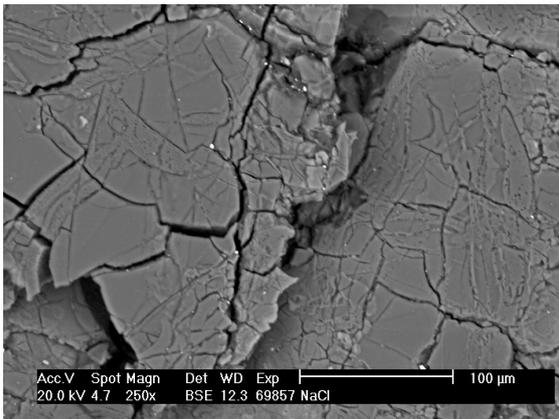


5: One of PSD functions of AE events in aluminium alloy  
Source: authors

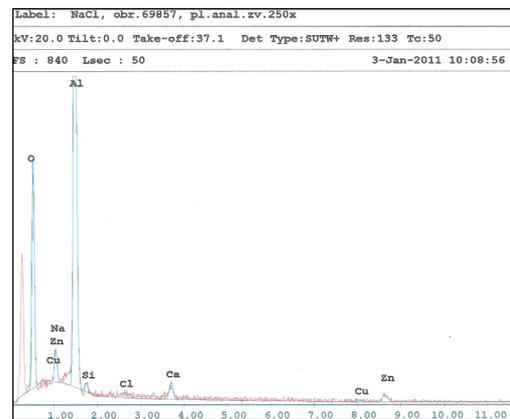
and transformed into a frequency domain and the evaluation of PSD maximum peaks was made.

The PSD (Power Spectral Density) function of acoustic emission events is a quantity property that indicates the power distribution in frequency

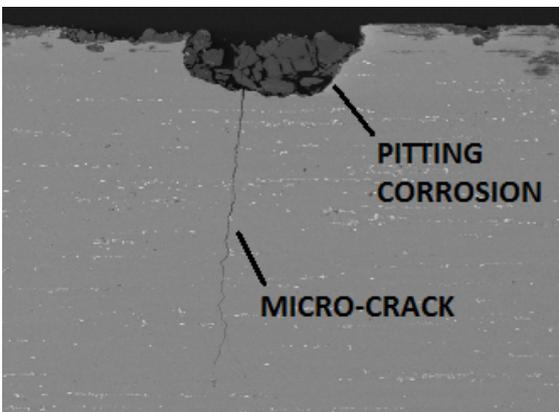
domain. On the graph of the PSD there is an important maximum (peak, extreme) which indicates the frequency transmitting most of the signal output power. Figure 5 shows the signal sample (left) and PSD function of the signal (right).



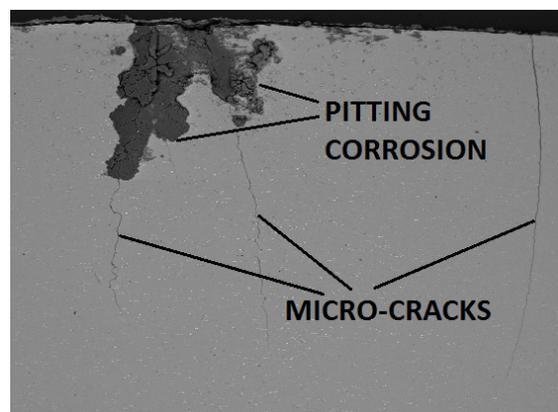
6:  $Al_2O_3$  structural analysis  
Source: BUT



7:  $Al_2O_3$  chemical composition  
Source: BUT



8: Micro-crack (specimen No. 2)  
Source: BUT



9: Micro-cracks (specimen No. 15)  
Source: BUT

In aluminium alloy showed during the experiment a specific type of AE events featuring background acoustic noise and very short pulse bar. In these events the PSD maximum was about 80 kHz (see Figure 5). Research and data analysis shows that these events indicate the pitting corrosion.

The next stage of the work deals with synergistic effects of corrosion and fatigue degradation of the aluminium alloy. The corrosion-degraded specimens were under cyclic loading up to micro – crack occurrence. Then, they were analyzed by electron – microscope at Brno University of Technology (BUT) research facility. The structure of surface created by corrosion ( $Al_2O_3$ ) is shown in Figure 6 and its chemical composition in Figure 7. This layer is brittle, cracked and has a plate characteristics.

AE method can indicate pitting corrosion in aluminium alloys. This is very important result of this research. Figure 8 and 9 show examples of pitting corrosion. The material was depicted after

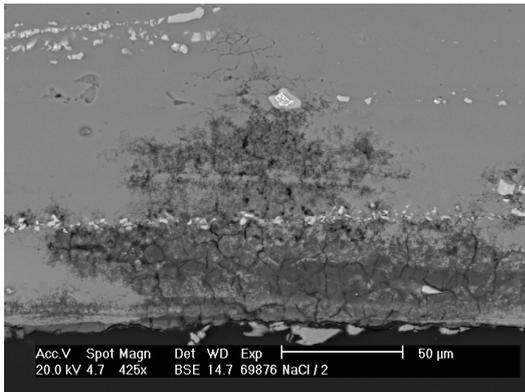
cyclic loading process. There are visible cracks which are indicated right in the pits. These micro-cracks can lead to the final fracture of material.

The cracks propagate usually from pitting corrosion locations. Few micro-cracks propagate also from inter-crystalline corrosion locations or from the actual surface (see Figure 9).

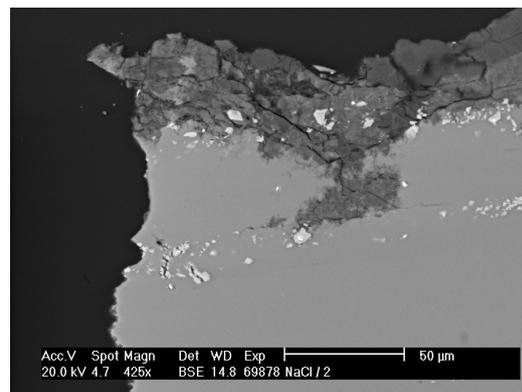
Figure 10 shows an inter-crystalline corrosion which can cause fatigue crack initiation. Figure 11 shows the fragmentation in fatigue crack initiation location. In this case, the final fracture in inter-crystalline corrosion location took place.

The main crack formation and then the fracture occur more often in pitting corrosion. Figure 12 shows percentage ratio between the cracks occurrence in different initiation locations of the 20 observed specimens.

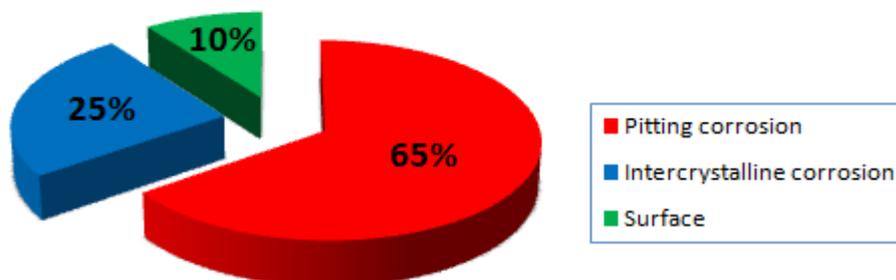
The graph on Figure 13 shows the number of micro-cracks initiated by pitting corrosion in each of 20 specimens.



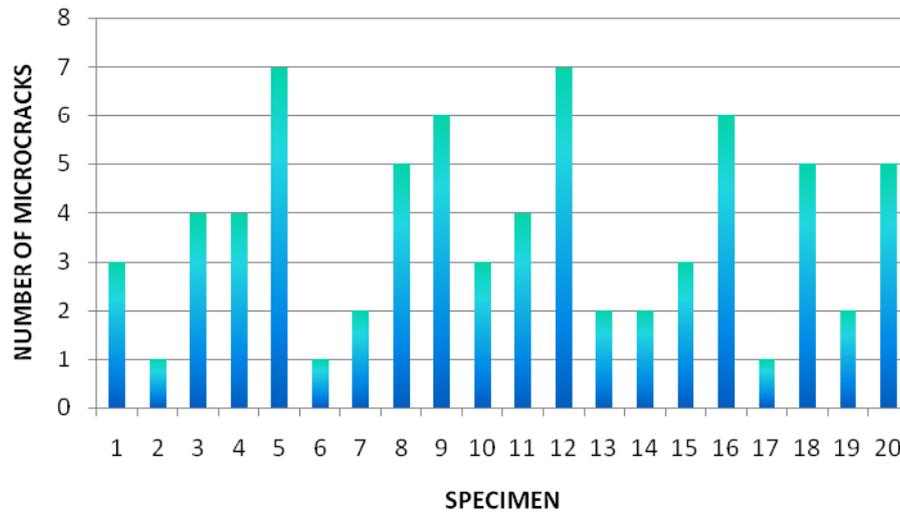
10: *Inter-crystalline corrosion*  
Source: BUT



11: *Fragmentation*  
Source: BUT



12: *Ratio of crack initiation locations*  
Source: Authors



13: Number of micro-cracks initiated in pitting corrosion in individual specimens  
Source: authors

## SUMMARY

The paper deals with the specific NDT method – acoustic emission (AE). AE allows for real-time monitoring of defect/corrosion development process. This work is focused on utilization of this method in the field of corrosion and fatigue degradation of aluminium alloys.

A set of aluminum alloy EN AW-7075 samples was subject to accelerated degradation process in NaCl corrosion chamber. Acoustic emission was monitored in for 21 days to detect corrosion process. The chamber can accelerate the corrosion in crypto-conditions with NaCl as much as 100 times. Final analysis has shown the signals of acoustic emission indicating the formation of pitting corrosion can be identified.

The specimens were subject to cyclic loading up to the formation of micro-cracks for practice simulation. The acoustic emission laboratory at Brno University of Technology was utilized for this part of the project. Fatigue micro-crack was supposed to develop in lower resistant area of material such as pitting or inter-crystalline corrosion. The time interval from micro-crack initiation to crack propagation is often very short and accidents happen unexpectedly. The formation of micro-cracks was identified by the electron microscope in the area of pitting corrosion. It is clear from the statistical evaluation above. Fatigue life of aluminium alloys was analyzed using AE. The images of the electron microscope made it possible to identify  $Al_2O_3$  surface layer, pitting corrosion, inter-crystalline corrosion, location of micro-crack initiation and the structure of fracture. In the statistical evaluation graphs (see Figures 12 and 13) we can see that the pitting corrosion is the most dangerous damage that significantly supports micro-crack initiation under cyclic loading.

The aim was to test a sophisticated measurement method that can evaluate the formation of pitting corrosion and subsequent formation of possible dangerous micro-cracks during the cyclic mechanical stress.

The paper demonstrates the possibility of corrosion degradation visualization using acoustic emission in real time. The identification of micro-cracks formation during the cyclical mechanical stress using AE has already been described in several scientific works. This project was focused on identification of dangerous pitting corrosion in aluminum alloys which can cause critical micro-cracks during applied mechanical stress. The main benefit is the possibility to identify AE signals during corrosion process and then avoid micro-crack formation and development.

In this paper, a method of AE was utilized. The corrosion process was visualized and thus it was possible to predict the material behavior. These results can be successfully applied in many scientific disciplines. Then, serious accidents can be prevented by knowledge of corrosion and fatigue process.

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