ACCELERATED CORROSION AND FATIGUE MONITORING OF ALUMINIUM ALLOY EN AW 7075

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Introduction

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 [1].

Acoustic emission (AE) is one of these methods. 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. [2].

The specimens were degraded under accelerated corrosion conditions and monitored using the AE testing. By means of laboratory tests and data analysis it is possible to effectively predict behaviour 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 localised 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 the synergy effect of fatigue and corrosion processes. The destruction process was monitored by the AE diagnostic method.

The aim is to demonstrate the usability of AE in corrosion and fatigue processes monitoring. A very important goal is to have a system for operative intervention in order to manage the functionality of components, even in case of the risk of damage or accident. Using microscope images (SEM), dangerous types of corrosion attack and localised crack initiation points during fatigue/static stress can be identified.

Methods and Equipment of the Investigation

Specimen Material

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

Table 1. ***Chemical composition of EN AW-7075 (%)***.

Material		Si	Fe	Cu	Mn	Mg	Cr	Zn	Al
AlZn6Mg2Cu	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 AE parameters, localisation 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 a throat segment of a reactor pressure vessel, a volume compensator and a pipeline network. Systems sensors can also act as electronic transmitters (pulsers) enabling the function check and calibration of sensors [3].

Corrosion Degradation

For the corrosion degradation, equipment made by the Liebisch Company was used. Figure 1 shows a salt chamber for the accelerated corrosion process. An accelerated corrosion test was carried out according to the ISO 9227 standard. The test was performed in a corrosive environment in the form of salt fog (atmosphere of NaCl) in concentration of 50 ± 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^{-3}. This test is usually used for metals and their alloys, metal coatings and organic coatings on metal surfaces [4,5].

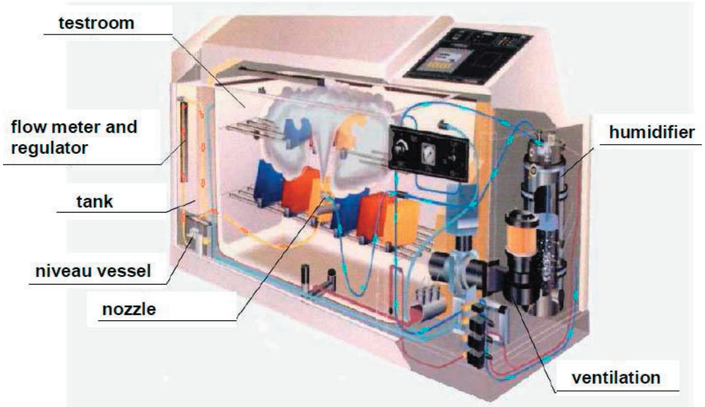

Figure 1. Liebisch salt chamber. *Source: www.liebisch.com*

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 analysed by Dakel XEDO AE 4.0 in 80 – 400 kHz frequency range. The measured dataset was stored on the hard drive of a standard PC. Table 2 shows configuration of the Dakel XEDO analyser [3,6].

Table 2. ***AE parameters used in the configuration of the Dakel – XEDO analyser***

Parameter	**Setting**
Gain of analyser	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	1000 words
Pretrigger	1000 words
Period	1000 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

Fatigue Degradation

The fatigue life was assessed on the specimens degraded by corrosion in the salt chamber for 21 days. The speed and the stage of fatigue degradation were sensed by the 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 behaviour was analysed using AE. Figure 2 shows the specimen mounted on testing equipment with the AE sensor attached [7].

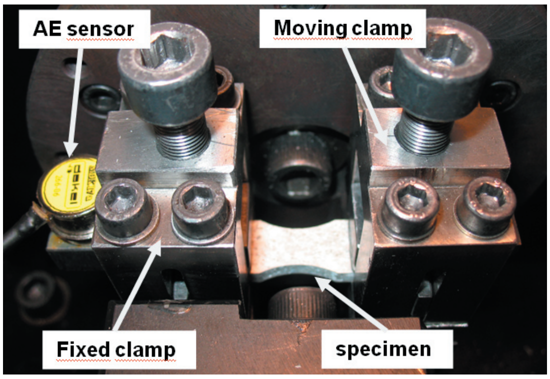

Figure 2. Rumul Cracktronic 160 with the specimen and the AE sensor.

The loading frequency is determined by the specimen stiffness. This frequency changes due to 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 a 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 [7, 8].

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 the fatigue life of the 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 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. The steel etalon showed a significant increase in RMS values at the beginning of the second day of the experiment. Then, the RMS of the 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).

The acoustic emission measured on aluminium does not correspond to that of the steel. Aluminium has a good corrosion resistance and it has the 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 immediately again in most environments [7, 9]. 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 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 below shows the signal sample (left) and PSD function of the signal (right).

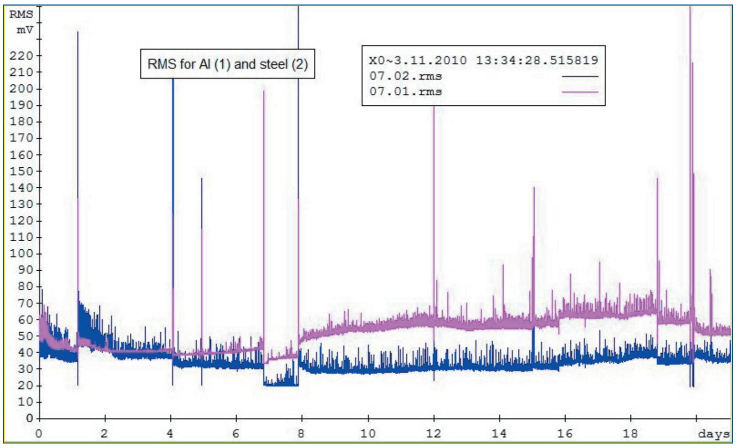

Figure 3. RMS of AE signal from aluminium alloy and steel

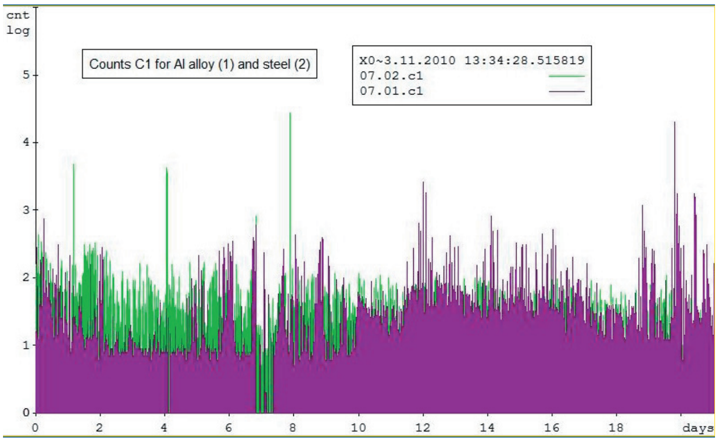

Figure 4. AE Counts C1 for aluminium alloy and steel

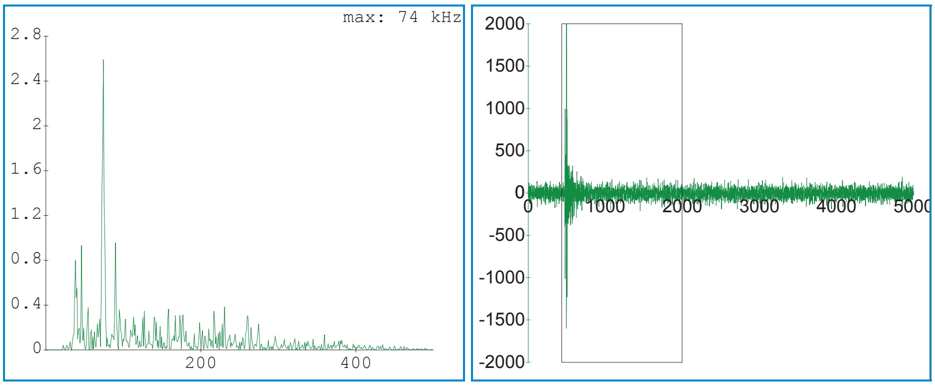

Figure 5. One of PSD functions of AE events in aluminium alloy

During the experiment, aluminium alloy showed 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). In accordance with the publications [7, 8] and [10] can be expected that 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 analysed 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 is shown in Figure 7. This layer is brittle, cracked and has plate characteristics.

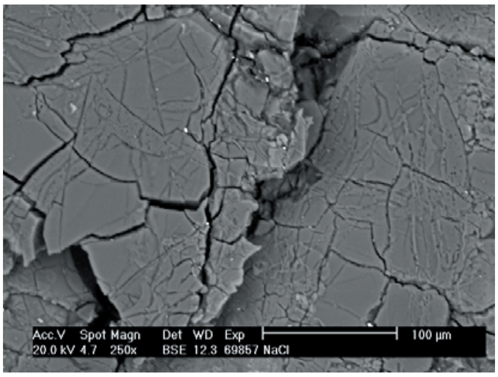

Figure 6. Al_2O_3 structural analysis
Source: BUT

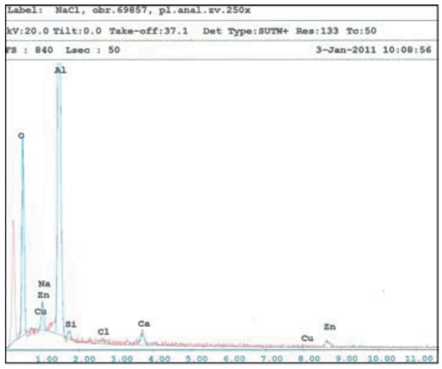

Figure 7. Al_2O_3 chemical composition
Source: BUT

AE method can indicate pitting corrosion in aluminium alloys. This is a very important result of this research and it builds on the findings described in publications [11, 12]. Figure 8 and Figure 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.

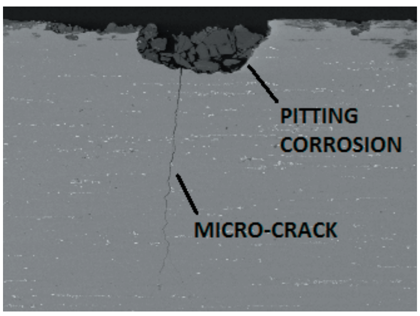

Figure 8. Micro-crack (specimen No. 2)
Source: BUT

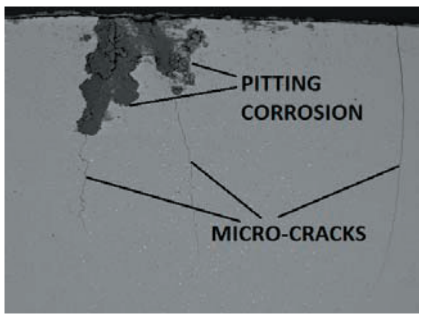

Figure 9. Micro-cracks (specimen No. 15)
Source: BUT

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 [14].

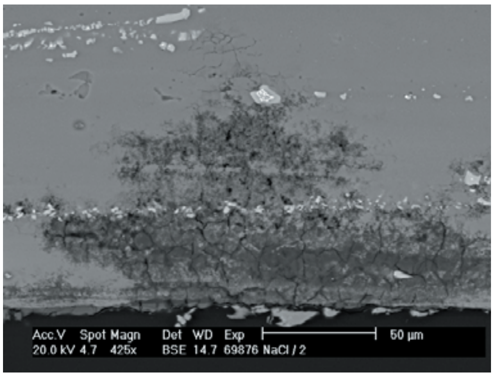

Figure 10. Inter-crystalline corrosion
Source: BUT

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.

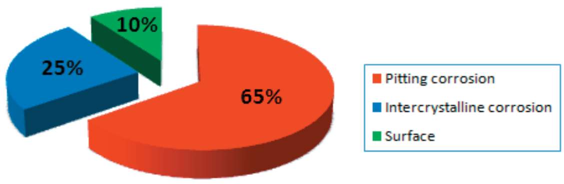

Figure 12. Ratio of crack initiation locations

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

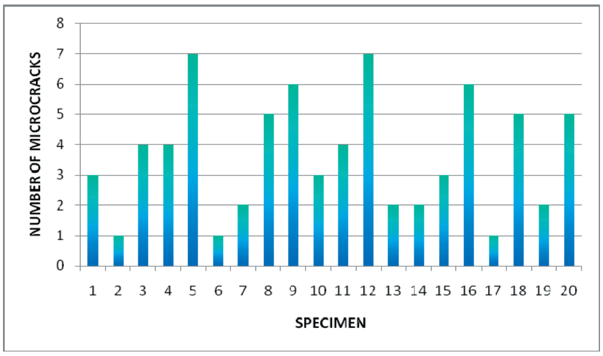

Figure 13. Number of micro-cracks initiated in pitting corrosion in individual specimens

Acknowledgments

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Figure 11 shows the fragmentation in fatigue crack initiation location. In this case, the final fracture in inter-crystalline corrosion location took place. This problem is described also in publications [13] and [15].

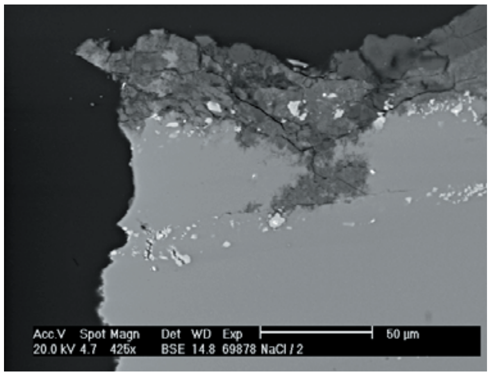

Figure 11. Fragmentation
Source: BUT

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ACCELERATED CORROSION AND FATIGUE MONITORING OF ALUMINIUM ALLOY EN AW 7075

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Summary

The paper is dedicated to synergy of corrosion and mechanical degradation for aluminium alloys. Monitoring of the degradation process was performed using the acoustic emission (AE) method. The authors discuss the possibility of using the AE monitoring system to identify various degradation stages of exposed specimens. There is described the principle of acoustic emission and its practical use possibilities. The problems of the fatigue process and mechanism of crack dispersion on corroded material are solved. The tested samples made from aluminium alloy EN AW 7075 are loaded on a high-cyclic mechanism by four-point bend for fatigue limit testing. With the use of an acoustic emission sensor interconnected with a PC are internal changes in the material monitored. This non-destructive method of material testing is used also for accelerated corrosion monitoring. Using this measurement system it is possible to observe the current status of the machines/devices and to prevent serious accidents.

Key words: acoustic emission, AE, corrosion, aluminium alloys, degradation, crypto-conditions, mechanical loading, fatigue loading, fatigue crack.

ALIUMINIO LYDINIO EN AW 7075 PAGREITINTOS KOROZIJOS IR NUOVARGIO TYRIMAS

Petr Dostál, Vojtěch Kumbár, Michal Černý, Artūras Sabaliauskas

Santrauka

Šiame darbe atliktas aliuminio lydinio EN AW 7075 korozijos proceso ir plyšio formavimosi, esant ciklinei apkrovai, stebėjimas akustinės emisijos metodu. Aprašytas akustinės emisijos principas ir praktinės jos panaudojimo galimybės. Tiriamas nuovargio procesas ir plyšio dispersijos mechanizmas ant korozijos pažeistos medžiagos. Atilikti keturių taškų ciklinio lenkimo eksperimentai su aliuminio lydinio EN AW 7075 bandiniais nuovargio ribai gauti. Akustinės emisijos metodu tirti medžiagos pokyčiai. Taip pat šis metodas taikytas pagreitintos korozijos poveikiui tirti. Šiuo metodu galima tirti mechanizmo (įrenginio) esamą padėtį ir užkirsti kelią gedimams atsirasti.

Prasminiai žodžiai: akustinė emisija, korozija, aliuminio lydinys, nuovargis.

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