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Acoustic Emission Response to Erosion-Corrosion and Creep Damage in Pipeline Systems

Libor Nohal[a], Pavel Mazal[a], Frantisek Vlasic[a]*, Marie Svobodova[b]

[a] *Brno University of Technology, Faculty of Mechanical Engineering, Technicka 2, Brno, 616 69, Czech Republic*
[b] *UJP Praha, a.s., Nad Kaminkou 1345, Prague, 156 10, Czech Republic*

Abstract

Pipeline system failures confirm that special attention must be paid to the main components of nuclear power plants in particular. One of the significant degradation factors in terms of integrity and residual life of these components is erosion-corrosion in piping systems and creep in high pressure pipelines of thermal power plants. This article deals with analysis of a set of steel samples with different degrees of degradation using acoustic emission method based on detection of elastic-stress waves in a material. Time domain and frequency domain characteristics of acoustic emission signals generated by different creep mechanisms are analyzed. The main task is to find a relationship between crack creation and propagation and acoustic emission response. Part of the solution is also the design and implementation of a diagnostic method for operation monitoring of the deterioration of the high-pressure piping systems at high temperature. The benefit should be a significant reduction in the risk of damage to important components and reduction of the probability of damaging pipe wall integrity potentially sensitive to erosion-corrosion.

Keywords: acoustic emission method; creep; crack; steam piping material

1. Introduction

Secondary circuit failures in nuclear power plants confirm that there is a need to pay due attention to the main components of this part of the nuclear power plant. One of the major degradation factors in terms of integrity and

* Corresponding author. Tel.: +420-541-143-240 . *E-mail address:* vlasic@fme.vutbr.cz

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residual life is erosion-corrosion and creep by International atomic energy agency (2007). There are several basic mechanisms that may contribute to creep in materials. The various classifications of these mechanisms are not always the same and sometimes they are more detailed or combined, depending on the points being emphasized by Kassner (2009). The classification used here is somewhat arbitrary, but follows a pattern commonly found in the literature: dislocation slip, climb, grain-boundary sliding, and diffusion flow caused by vacancies. In the ranges of temperature and stress commonly encountered in engineering applications, the most significant creep mechanism at a microstructural level is the motion of dislocations, accompanied by the diffusion of vacancies by Lupinc (1981).

Non-destructive testing (NDT) gives vital information for material characterization including quantitative determination of the size, shape and location of a defect or anomaly thus enabling structural integrity assessment of a component. However, conventional NDT techniques require a great deal of process disruption and preparation, for example, drainage of material from inspection specimens by Jomdechaa et al. (2007). Acoustic emission (AE) inspection has been introduced to the problem and has gained popularity; thanks to its real-time response. AE has been very widely applied especially in the areas of quality control in manufacturing operations and process monitoring; also it is very useful applications of composite structures (advanced aerospace materials, fiberglass) and can also be employed in research applications and quality control in manufacturing operations by Gholizadeh et al. (2015) and Morizet et al. (2016) or Sposito et al. (2010). In this study, time domain and frequency domain characteristics of AE signals generated by different creep mechanisms are investigated in detail.

Nomenclature

AE	acoustic emission	RMS	root mean square of AE signal
NDT	non-destructive testing	AEE	acoustic emission event
ČSN	Czech technical standard	FFT	Fast Fourier transform
TOFD	Time Of Flight Diffraction	PSD	power spectrum density of AE hit

2. Experimental procedure

2.1. Material and creep testing

The tested material comes from an operationally exposed high-pressure steam pipeline (from steel ČSN 15 128.5 (DIN 14MoV6-3) of nominal dimensions OD 273 x 25 mm) of the K3 boiler in power plant Opatovice a.s. from weld No 10. This weld was cut after 213,543 operating hours at 528.4 °C and a pressure of 9.6 MPa due to the negative result of NDT control (transmission test and TOFD), which indicated a discontinuity weld not allowing further operation. In 2018, a total of 8 longitudinal creep specimens through a weld seam in the middle of specimen were produced from this material. The orientation and dimensions of the creep specimen (allowing the welding of two waveguides) are shown in the diagram in Fig. 1.

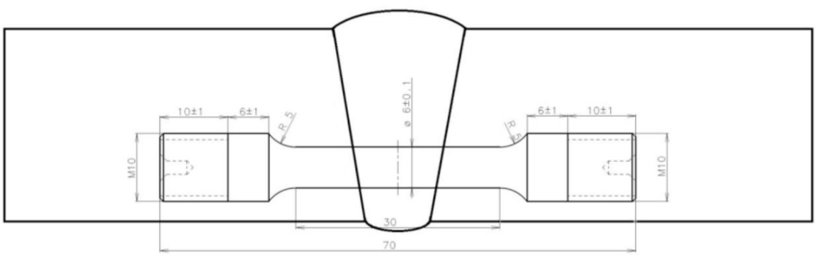
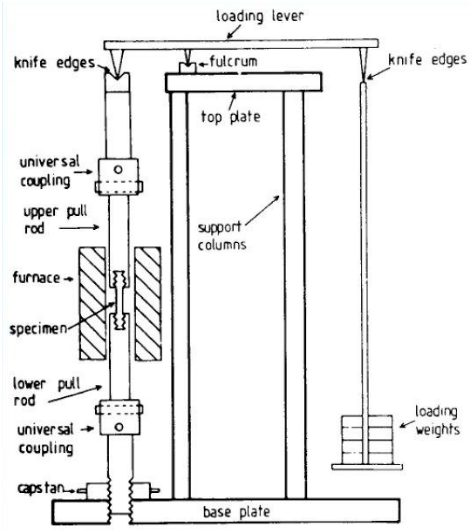


Fig. 1. Orientation and dimensions of the creep specimen taken from an operationally exposed homogeneous weld joint of steel 15 128.5.

Uniaxial tensile creep tests were performed on a three-position machine Zst 2/3, manufactured by VEB WERKSTOFF PRUFMASCHINEN LEIPZIG (see Fig. 2b). The test conditions summarize these parameters: ϕ diameter of the test rod (6 mm), F is the loading force, σ is a stress relative to the ϕ diameter, T is the temperature of the test, t_r is the time to fracture, A5 (ε) is the deformation at fracture and Z is the contraction (see Fig. 2a). The furnace temperature is controlled by three calibrated type K thermocouples and recorded by the ADAM module (Advantech manufacturer) to the computer. The creep extension is continuously measured using a sensitive incremental rotary sensor (wired over the pulley) and written to a Raspberry Pi miniature computer (sensing time, angle of rotation of the measuring pulley and recalculated specimen elongation).



a)

b)

Fig. 2. (a) Typical creep test setup, (b) Three-position machine for creep test Zst 2/3 (VWPL).

2.2. Acoustic emission testing

The acoustic emission recording is transmitted from the DAKEL-ZEDO monitoring system, which stores signal throughout the experiment at 2 MHz sampling frequency. The AE signal from the specimen is monitored by two waveguides using MDK-13 piezoelectric magnetic transducers during the entire creep test. The signal from the sensor, which includes an integrated preamplifier, is detected at a gain of 10 dB with frequency range from 50 to 500 kHz.

The basis of the AE evaluation is analysis of the overall noise background. For this purpose, during the creep test, the ZEDO system monitors the envelope, energy and root mean square (RMS) of the continuous signal. The system also evaluates the number of AE events (AEE) that exceed normal noise background and the shape of AE signal – hit AE of these AEE. Also the frequency spectrum, especially FFT analysis of the signal, and source location of the AEE play an important role in the evaluation of the test (those will be discussed in detail below).

3. AE results

For the purpose of this research, it was necessary to obtain sufficient data in a relatively short period of time. Therefore, creep tests were accelerated by appropriate settings. The response of the AE signal to creep deformation was very similar and resembled a fatigue test in its character, where we can detect high activity in the first phase, very quiet in the second phase and in finally phase strong AE again.

In addition to the basic setup options, AE device allows to detect AE hits from three adjustable threshold levels (hit detector 0, 1, 2) where detectors 0 and 1 were set to a fixed value 0.31% and 0.63% of the range and detector 2 was set to a floating threshold of 200% noise level. As a typical representative of the AE response to the creep test, specimen D18 was selected. During creep tests, individual AEE and RMS values were detected, but in particular the number of detected AE hits corresponds to the rate of creep deformation (see Fig. 3b).

There is also a difference in the overall deformation achieved in connection with time to fracture. However, continuous creep curve recording (creep curve) in all cases corresponded to the expected three-stage course, see Fig. 3a, although the exact identification of the transition from one stage to another is not always simple. During the test, especially in the first and last phase, we can see several significant peaks corresponding to the applied degradation mechanism (marked by arrows in Fig. 3b).

In the primary stage (phase 1), RMS shows higher values and there is a higher number of AE hits. RMS values gradually decrease to minimal with only occasional fluctuations to higher values when transition to the secondary stage (phase 2) of steady creep deformation (minimum creep rate). The number of AE hits will decrease significantly and remain constant until the tertiary stage, when AE hits number is rapidly increasing.

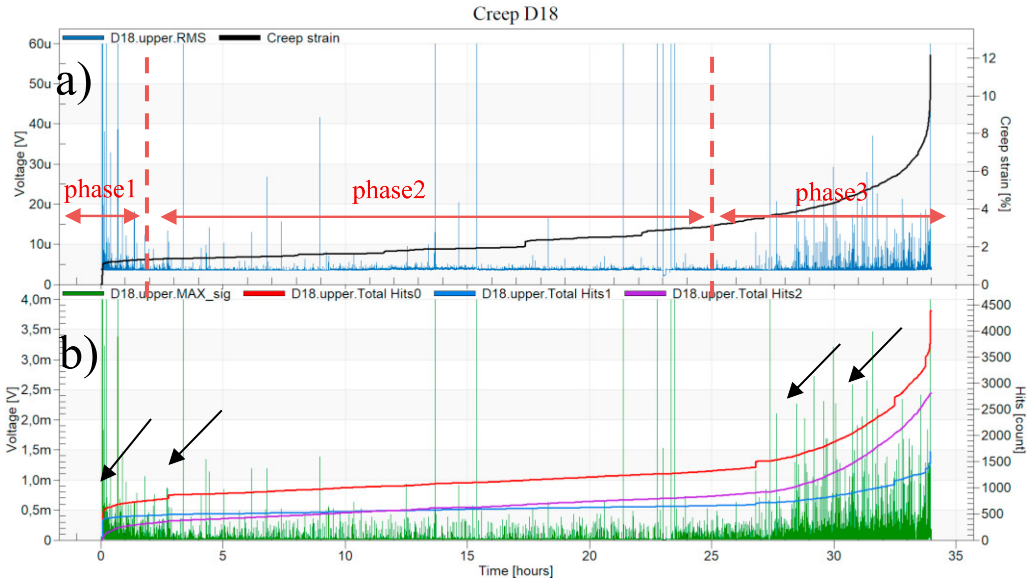


Fig. 3. (a) Time dependence of RMS and creep strain, (b) Time dependence of AE signal envelope and cumulative hits at three thresholds.

RMS near the time to fracture grows extremely and reaches up to three times the values in the primary stage. This characteristic is clearly visible in histogram of AE hits during the entire creep test in Fig. 4. The key issue was to design a suitable filter to exhaust disturbing sources, especially ambient noise and furnace sources. Therefore, noise background measurements were performed twice in laboratories (in creep machine hall and in INSTRON tensile test hall). Proposed boundaries (dashed red line) of each stage were determined by creep curve shape estimation and degradation mechanisms applied in creep process were assigned.

In addition to the graphical evaluation of AE records, all AE hits were converted from time to frequency domain by Fourier transform. From obtained power spectrum density (PSD) of AE hits can be easily determined their dominant frequencies that we can display in creep test graph (see Fig. 5). Each point in the graph belongs to one AE hit and the level of achieved FFT amplitude is processed by a color scale. Energy of AE hits is part of the graph. It is clear, AE hits in the last stage appear at higher frequencies while during the entire test the frequency is about 160 kHz.

Another tool to improve measurement accuracy and filtering of irrelevant signals was source location analysis. Therefore, two waveguides were made on each side of the specimen (2.4 mm non-magnetic stainless steel wire AISI 316L), see Fig. 6. The first one (431 mm in length) was led up over the furnace (channel A), the other one (445 mm in length) down below the furnace (channel B). Based on the arrival time to each sensor, wave propagation velocity of 4600 m/s was calculated. After removing AE sources near the sensors, a localization map of AE sources for the entire creep test was constructed. The cumulated locations of AEE detected throughout the test are observed arbitrarily distributed and diffused along the length of the specimen.

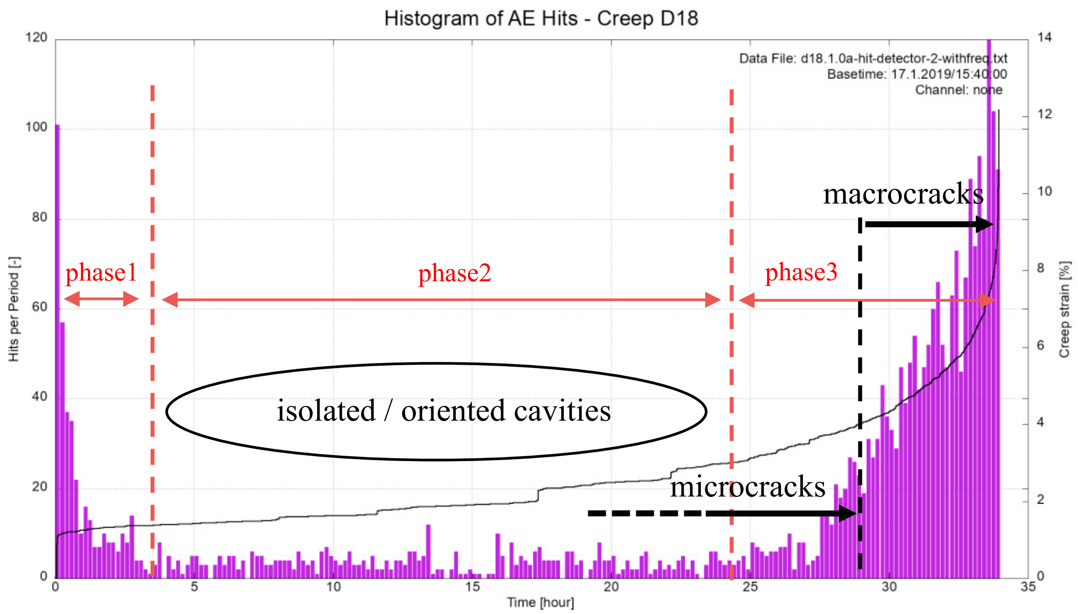


Fig. 4. Histogram of AE hits during the entire creep test (period hits = 600 sec).

Then, AEE begin to localize near the lower waveguide of channel B in the zone of the maximum tensile stress (AREA1 in Fig. 6). Amplitudes of AE events in this region have higher values than in the rest of events. For more accurate AE signal, it is convenient to focus only on AEE from AREA1 and search other connections in creep process.

In order to find a connection between creep damage and AE response, a detailed metallographic evaluation of the damaged specimen was performed, including fractographic documentation of both fracture surfaces. However, this section is not included in this article and will be published in another paper.

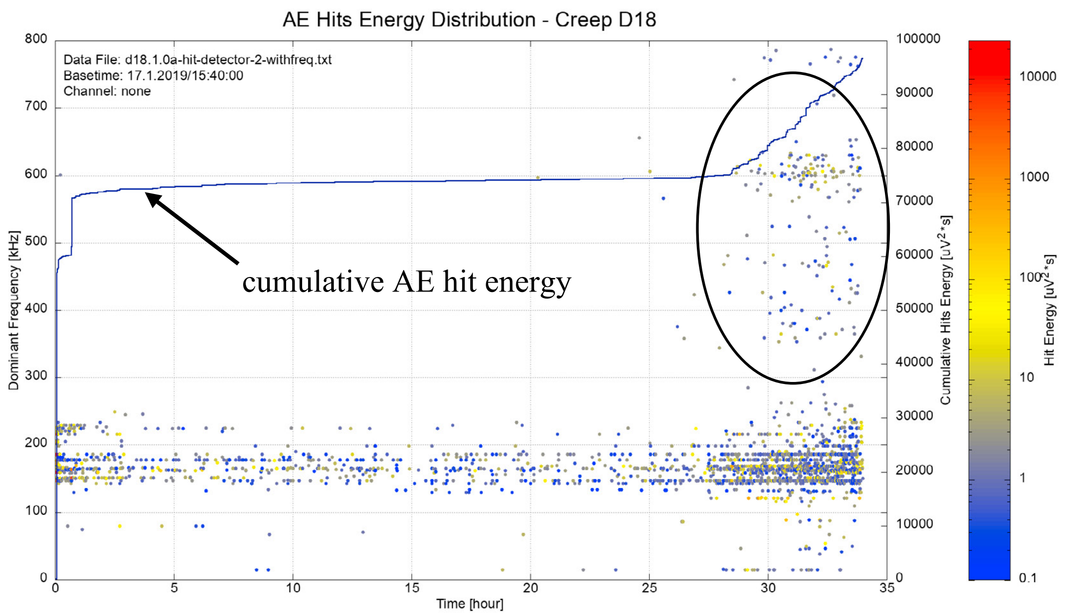


Fig. 5. AE hits energy distribution of D18 specimen during the entire creep test.

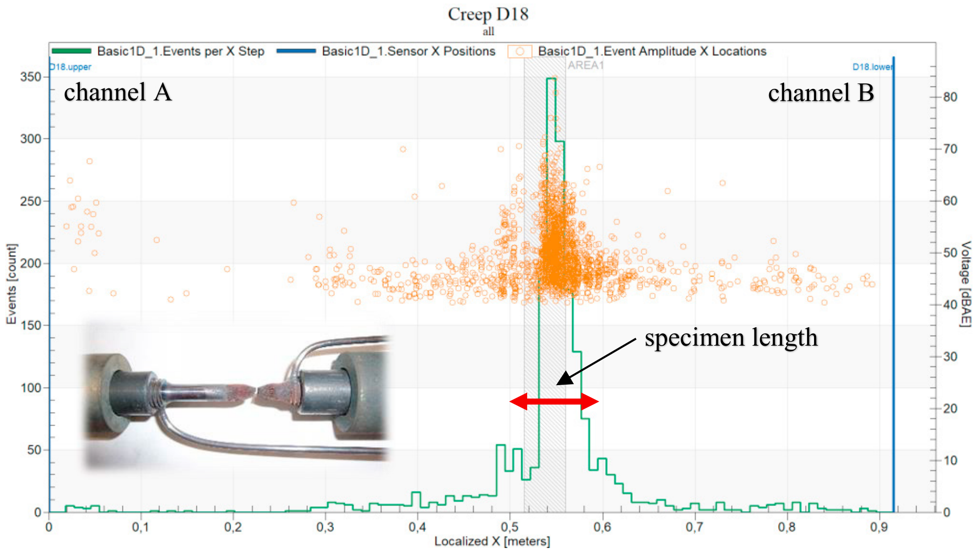


Fig. 6. Damage localization map of AE sources during the entire creep test.

4. Conclusion

In this article tested material coming from an operationally exposed high-pressure steam pipeline was subjected to a detailed analysis focused mainly on the filtration of ambient noise signal - using frequency filters and source location of acoustic emission events to the place of crack formation. It has been found that development of AE hits corresponds to the increase of creep rate in the transition to the tertiary stage of creep process.

AE diagnostics is a contemporary and perspective method of non-destructive testing for this area because, unlike conventional ultrasonic diagnostic methods used for local diagnostics, it is useful for long-term operational monitoring of pipeline condition. In addition, this method allows multiple signals to be simultaneously received, remotely transmitted, and processed in AE system.

Acknowledgements

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