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AE fatigue experiments on tanks test samples with artificial pre-cracking

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Abstract

The acoustic emission (AE) method is well studied for its capability to detect and locate discontinuity that evolve in time, when a pressure tank is charged with a greater load than the usual one. When the discontinuity is a crack the AE is able to follow the nucleation and the propagation of the defect in the material. For this paper, experiment on pre-cracked samples with different notch shape are presented. The samples have been loaded with fatigue cycles and the acoustic activity during the tests has been recorded. The stress was always positive to keep the notched side in traction during the test. During the test AE signals become relevant when the load leads plastic strain near the notch. We noticed an increase of activity when the plasticity advances with a stepped shape. This stepped shape of the number of the events versus time agrees very well with the crack nucleation and its evolution to a fully developed crack.
We applied the fractal analysis method to these experiments, to verify the correlation between the fractal dimension (D_t), the applied stress and the order/disorder of the material of the sample. The fractal analysis method is capable to follow the damage status of the sample, while fatigue test.

Keywords: Acoustic Emission; Non-Destructive Testing; Crack Nucleation; Damage Evolution; Machined Notch

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1. Introduction

Acoustic Emissions (AE) are elastic stress waves emitted from local sources inside a structure subject to a load (Fang and Berkovits (1995)) when irreversible phenomena evolve within the material (breakage of impurities, movement of dislocations and onset and evolution of new or pre-existing cracks) (Davis (1994)). Due to this correlation between acoustic activity and progress of damage (Carpinteri et al. (2010), Kurz et al. (2006)), Acoustic Emission Testing (AET) successfully employs AE to detect and localize defects while developing in a component (Grosse and Othsu (2008)). In fact, AE characteristics, such as number of occurrence, amplitude and frequency, and their evolution over time, offer a way to supervise the damage process (Shiotani et al. (1994), Watanabe et al. (2010), Muralidhara et al. (2010), Vidya Sagar et al. (2010)). The distinction between passive and active non-destructive AE techniques depends upon the trigger of vibration: the defects themselves as spontaneous sources in the first case, an external device that exploits the reflection of mechanical waves at the flaws in the second (Grosse et al. (2008), Tabatabaeipour et al. (2014)). Reflection phenomena of waves at material boundaries strongly affect the physics of the propagation: at first, a wave behaves as in an infinite medium (bulk wave, BW) until the presence of boundaries (if any) alters its motion (guided waves, GW) (Rose (2014)). GW are preferred in the field of non-destructive testing (NDT) for their enhanced scanning capability, as long as the tested structure can act as a waveguide (Li et al. (2016)). AET appears particularly advantageous for real-time monitoring of pressured vessels: a permanent network of sensors can allow for a continuous supervision over the health state of the system, with the possibility of targeted interventions only when needed. Although the life span of a ground steel tank is estimated at approximately 40 years, corrosion can significantly reduce this time lapse, triggering the necessity of a constant control over its structural state (Maheri and Abdollahi (2013)). AE methods have been successfully employed in several structural fields: deformation and damaging of materials (Biancolini et al. (2007)); fracture mechanics (Huang et al. (1998), Biancolini et al. (2019), Berkovist and Fang (1995)); composite materials (Hamstad (2000)), concrete (Ohtsu (2015)) and rock mechanics (Manthei et al. (2000), Gregori et al. (2005)); fatigue of metals (Hamel et al. (1981), Lee et al. (1996), Biancolini et al. (2006)); life assessment of mechanical components (Mba (2002), Augugliaro et al. (2013), Rauscher (2005)) and corrosion monitoring (Pollock (1986)).

In this paper, we report results from an experimental campaign on fatigue loaded steel specimens. Both notched and sound specimens were employed for the tests and two typologies of notch were considered. During the cyclic loading, AE were recorded from the material, with the purpose to establish a correlation with damage evolution. Fractal analysis (Biancolini et al. (2006)) supplies an interpretation method for the AE signals, albeit more traditional strategies were also possible (Builo and Popov (2001)). The box-counting method determines the fractal dimension D_t of the AE time series. When D_t is around unity, events happening in the material are considered uncorrelated, as the result of a disordered pattern of sources. On the contrary, when D_t tends to zero, the system is evolving towards a higher degree of organization, with a change in the structure approaching.

2. Experimental campaign

The experimental campaign (still ongoing) considered rectangular un-notched and notched specimens of steel, subjected to fatigue load by periodic three-point bending. During the tests, AE were registered from the material, in order to establish a correlation with the damage process. The positioning of the load on the specimen was such to avoid compression at the notch (if any), with a stress value in the flawed area alternating between zero and a tensile positive peak.

The experimental setup was constituted by:

- mechanical load machine
- 2 piezoelectric sensors Vallen VS150-RIC
- data acquisition system and post-processing software

Experiments proceeded in load control, with a constant monitoring on displacements. The piezoelectric sensors were applied directly on the specimens, as showed in Figure 1.

Fig. 1. A specimen with the sensors attached.

The post-processing software acquired and processed only AE originated within the specimens, filtering out external noise. Tested specimens were rectangular 400x40 mm and 5 mm thick, extracted from the tank manufacturing process just before the calendering stage. The material was steel P355N with the characteristics reported in Table 1.

Table 1. Characteristics of steel P355N.

Parameter	Value
Young's modulus	210000 MPa
Poisson's ratio	0.3
Yielding stress	355 MPa
Ultimate stress	490-630 MPa

Specimens were simply supported at the extremities (distance between supports = 300 mm) and cyclically loaded in the middle. As regards load intensity, the force on sound specimen was 300 N, within the elastic field. A higher load, able to plasticize the notched section, acted on the machined samples. In particular, notches of two different severity were considered:

- circular notch 1 mm deep (mill diameter 51 mm) and 0.15 mm wide (Figure 2 above)
- through notch 1mm thick (Figure 2 below)

Load intensities associated to the two cases were 900 N and 800 N respectively.

Fig. 2. Details of the considered notches with their CAD representations: type 1 above and type 2 below.

Tests were conducted over a high number of cycles for sound specimens, while for notched specimens relatively few cycles were sufficient to produce a fracture. The acoustic events of interest were located at +-50 mm from the notch, measured characteristics of each acoustic signal were its location, amplitude and energy. Each acoustic phenomenon whose source was located in the specimen and with an amplitude exceeding 30 dB is indicated as 1 hit.

3. Results and discussion

At the end of the fatigue test, sound specimens reported no damage and no significant AE activity was detected during load application. This is in agreement with theoretical considerations associating AE with irreversible damage. Relevant AE were recorded during the fatigue tests on both types of machined samples. For type 1 notched specimen, fracture appeared after 17500 cycles at 900 N. Figure 3 shows type 1 cracked specimen after liquid penetrant testing.

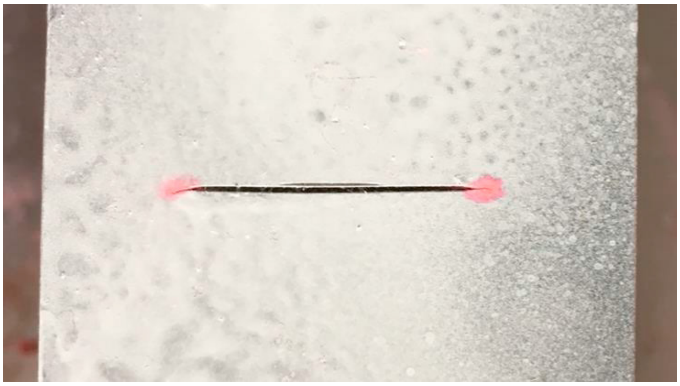

Fig. 3. A fatigue crack highlighted by the dye penetration test for a specimen with the type 1 notch.

The graph of the Cumulative number of hits vs the Number of cycles (Figure 4) and the graph of the Cumulative energy vs the Number of cycles (Figure 5) present a stepped shape, smoother the first, definitely abrupt the second, but both related to isolated acoustic emissions at a high level of energy.

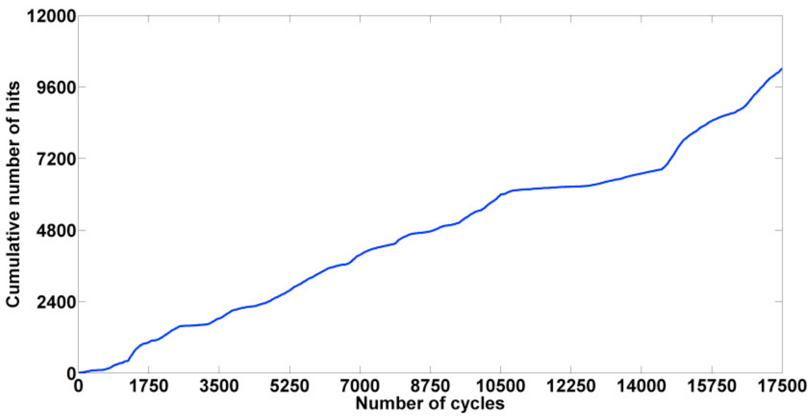

Fig. 4. Cumulative number of hits vs number of cycles for the type 1 notched specimen.

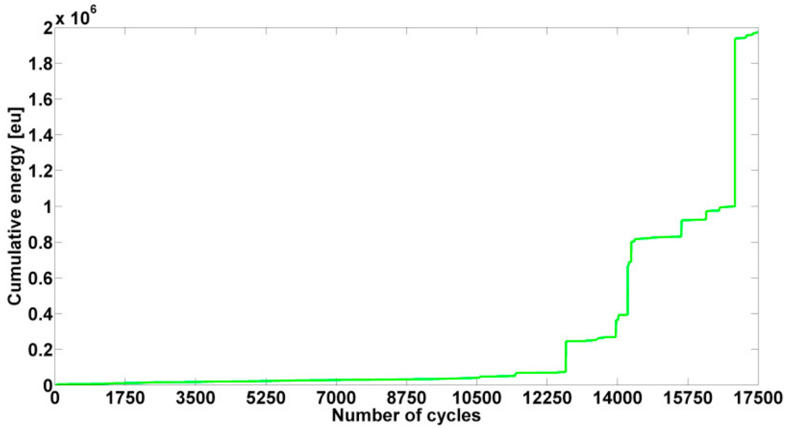

Fig. 5. Cumulative energy vs number of cycles for the type 1 notched specimen.

Fractal analysis associates a physical interpretation to the fractal dimension D_t of a signal: when $D_t = 1$ the system has a completely disordered pattern of sources, when Dt tends to 0 the system is evolving towards a better organized structure of damage. Figure 6 compares the fractal dimension D_t of the registered hits over time (above) with their representation as green dots in a Amplitude vs Time diagram (below). As can be observed, D_t oscillates throughout the test, which seems to suggest a step-wise progression of damage. When the specimen is approaching to failure (the portion between the dashed lines), a low value of D_t is encountered over many cycles, with a lower occurrence of emissions but at a higher energy level. This stepped progression agrees very well with the crack nucleation and its evolution to a fully developed crack.

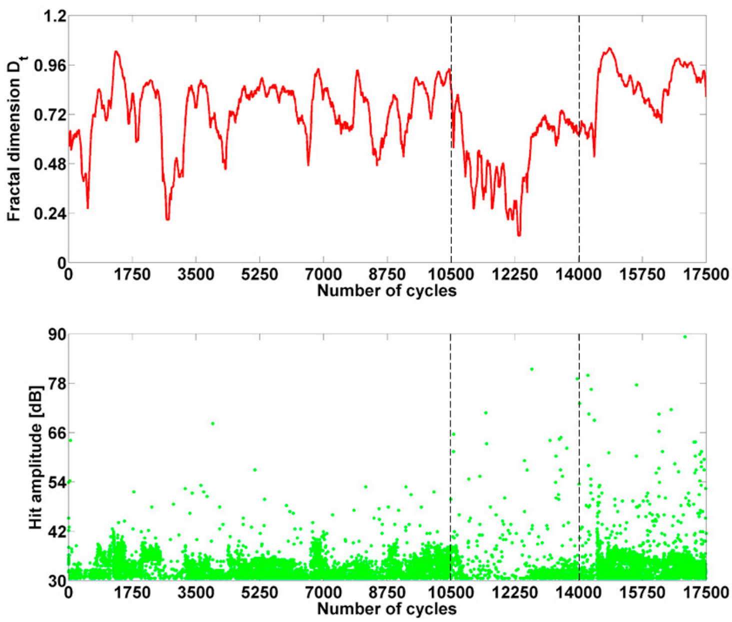

Fig. 6. Type 1 notched specimen, fractal dimension D_t of the registered hits over time above and their representation as green dots in a Amplitude vs Time diagram below.

Fig. 7. A fatigue crack is well visible along the slit of the type 2 notched specimen.

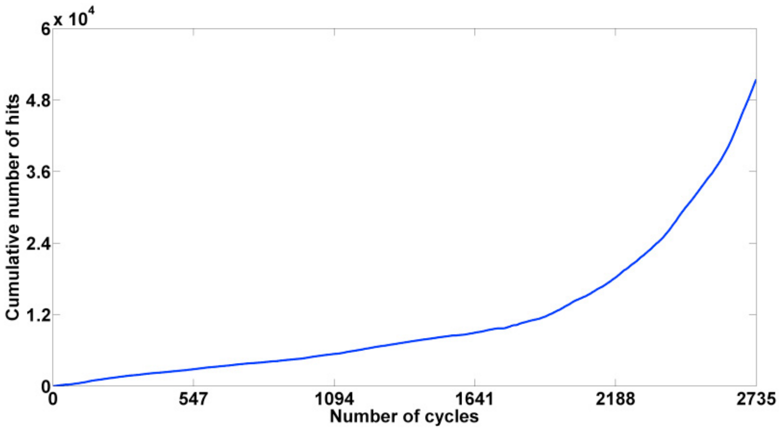

Fig. 8. Cumulative number of hits vs number of cycles for the type 2 notched specimen.

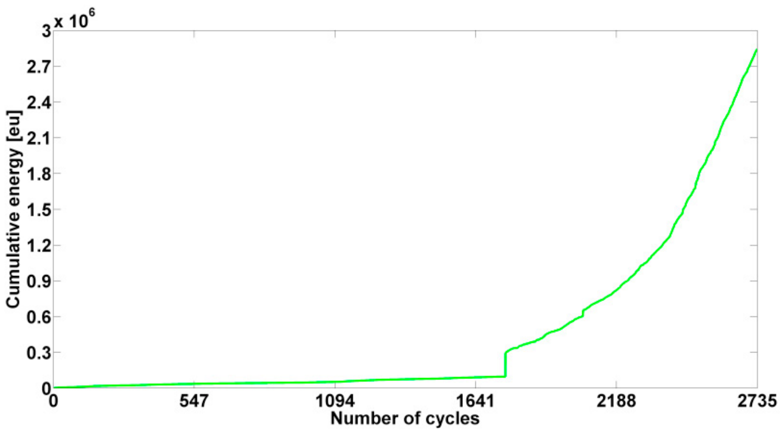

Fig. 9. Cumulative energy vs number of cycles for the type 2 notched specimen.

Fracture occurred after 2735 cycles at 800 N for type 2 notch (Figure 7). The graph of the Cumulative number of hits vs the Number of cycles (Figure 8) and the graph of the Cumulative energy vs the Number of cycles (Figure 9) show homogeneously rising curves. This suggests a rapid and continuous process for damage evolution. Fractal analysis, which can capture the spotted nature of several phenomena, is omitted for type 2 notch.

4. Conclusions

Rectangular steel specimens were subjected to fatigue test by three-point bending, Acoustic Emissions (AE) emitted during the cycles were received and registered. Both sound and notched specimens were considered in order to establish a correlation between the acoustic signal and damage progression inside the material. At the end of the tests, sound specimens reported no fracture as well as no significant AE were detected. Machined specimens divided into 2 types, according to the severity of the notch, underwent low-cycle fatigue tests until fracture. AE activity for the notched specimens was significant and featured characteristics related to notch severity.

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References

Auguglìaro, G., Brini, F., Brutti, C., Lazzaro, D., 2013. A.E. parameters to evaluate damaging process in structures. 8th E-GLEA, Buenos Aires, Argentina.
Berkovist, A., Fang, D., 1995. Study of fatigue crack characteristics by acoustic emission. Eng Fract Mech 51, 3.
Biancolini, M.E., Brutti, C., Chiappa, A., Salvini, P., 2019. Artificial pre-cracking of tanks test samples for AE detection tuning. 1st EPERC International Conference, Rome, Italy.
Biancolini, M.E., Brutti, C., Paparo, G., Zanini, A., 2006. Fatigue crack nucleation on steel, Acoustic emission and fractal analysis. International Journal of Fatigue 28, 1820–1825.
Biancolini, M.E., Brutti, C., Paparo, G., Zanini, A., 2007. Acoustic emission monitoring of damage evolution in mechanical materials. Proc. of GLEA 5, Oberà, Argentina.
Builo, S.I., Popov, A.V., 2001. Acoustic emission methods for assessing the process of damage accumulation in estimating remaining service lives of heavily loaded structures. Russ J Nondestructive Testing 37, 9, 636–643.
Carpinteri, A., Cardone, F., Lacidogna, G., 2010. Energy emissions from failure phenomena: mechanical, electromagnetic, nuclear. Exp Mech 50, 1235–1243.
Davis, J.R., 1994. ASM handbook. Non-destructive evaluation and quality control, vol. 17. Materials Park (OH). ASM International.
Fang, D., Berkovits, A., 1995. Fatigue design model based on damage mechanisms revealed by acoustic emission measurements. Journal of Engineering Materials and Technology. Transactions ASME 117, 201–208.
Gregori, G.P., Paparo, G., Poscolieri, M., Zanini, A., 2005. Acoustic Emission and released seismic energy. Natural Hazards and Earth System Sciences 5, 1–6.
Grosse, C.U., Othsu M., 2008. Acoustic Emission Testing. Springer-Verlag Berlin Heidelberg.
Hamel, F., Bailon, J.P., Bassim, M.N., 1981. Acoustic emission mechanism during high-cycle fatigue. Eng Fract Mech 14.
Hamstad, M.A., 2000. Thirty years of advances and some remaining challenges in the application of acoustic emission to composite materials, in "Acoustic Emission – Beyond the Millennium". Kishi, T., Ohtsu, M., Yuyama, S., (Ed.). Tokyo, Japan, Elsevier, pp. 77–92.
Huang, M., Jiang, L., Liaw, P.K., Brooks, C.R., Seeley, R., Klastrom, D.L., 1998. Using Acoustic Emission in Fatigue and Fracture Research. JOM 5, 11.
Kurz, J.H., Finck, F., Grosse, C.U., Reinhardt, H.W., 2006. Stress drop and stress redistribution in concrete quantified over time by the b-value analysis. Struct Health Monit 5, 69–81.
Lee, C.S., Park, C.G., Chang, Y.W., 1996. Precise determination of fatigue crack closure in al alloys. Mater Sci Eng A216, 131–138.
Li, X.X., Zhou, S.Q., 2016. Assessing damages in pipes through circular distribution of ultrasonic guided wave reflections from defects, Chemical Engineering Transactions 51, 541–546.
Maheri, M.R., Abdollahi, A., 2013. The effects of long term uniform corrosion on the buckling of ground based steel tanks under seismic loading. Thin-Walled Structures 62, 1–9.
Manthei, G., Eisenblatter, J., Spies, T., 2000. Acoustic emission in rock mechanics, in "Acoustic Emission – Beyond the Millennium". Kishi, T., Ohtsu, M., Yuyama, S., (Ed.). Tokyo, Japan, Elsevier, pp. 127–144.

Mba, D., 2002. Applicability of acoustic emissions to monitoring the mechanical integrity of bolted structures in low speed rotating machinery: case study. Ndt & e International 35, 5, 293–300.

Muralidhara, S., Raghu Prasad, B.K., Eskandari, H., Karihaloo, B.L., 2010. Fracture process zone size and true fracture energy of concrete using acoustic emission. Construct Build Mater 24, 479–486.

Ohtsu, M., 2015. Acoustic Emission and related non-destructive (NDE) techniques in the fracture mechanics of concrete. Fundamentals and applications. Woodhead Publishing Series in Civil and Structural Engineering 57, Elsevier.

Pollock, A.A., 1986. Acoustic emission capabilities and applications in monitoring corrosion. Corrosion Monitoring in Industrial Plants Using Nondestructive Testing and Electrochemical Methods. ASTM International.

Rauscher, F. 2005. Pressure test and acoustic emission examination. Shaker Verlag, Aachen.

Rose, J.L., 2014. Ultrasonic guided waves in solid media. Cambridge University Press, New York USA.

Shiotani, T., Fujii, K., Aoki, T., Amou, K., 1994. Evaluation of progressive failure using AE sources and improved b-value on Slope Model Tests. Progr Acoust Emiss 7, 529–534.

Tabatabaeipour, M., Hettler, J., Delrue, S., Van Den Abeele, K., 2014. 11th European Conference on Non-Destructive Testing (ECNDT 2014). Prague, Czech Republic.

Vidya Sagar, R., Raghu Prasad, B.K., Karihaloo, B.L., 2010. Verification of the applicability of lattice model to concrete fracture by AE study. Int J Fract 161, 121–129.

Watanabe, T., Hosomi, M., Yuno, K., Hashimoto, C., 2010. Quality evaluation of shotcrete by acoustic emission. Construct Build Mater 24, 2358–2362.