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Acoustic Emission of Composites Structures: Story, Success, and Challenges

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Abstract

This short paper is devoted to Acoustic Emission (AE) Nondestructive Testing. It's focused on the state-of-the-art of its application on composites, from the 1960's until now. The major realizations via this technique are carried out. Examples underlying the maturity of AE are debated. To continuously improve the reliability of this technique, many worldwide researchers are hardworking; some perspectives are discussed.

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1. Motivation

Thanks to their attractive advantages (Good anti-corrosion performance, long service life, light convenient installation and transportation, low thermal conductivity, small thermal stress, good electrical insulating property, high specific strength, reasonable mechanical property…), composite structures are in increasing use in various fields. However, they are not immune to different structural defects, which can occur either during manufacturing or in service-life, such as delamination, debonding, fiber fractures. Many nondestructive techniques can be used to contribute in preventive and curative maintenances of this kind of structures. AE, which is a phenomenon whereby transient elastic waves are generated by defect(s), occupies a strong position among these techniques. The success of this technique is linked to advanced signal processing and statistics techniques, experimental feedback and procedures, high-tech instrumentation, and modeling. The current short paper tries to provide an overview of AE and its application on composite structures, and devoted to large public and no background is needed.

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2. AE: short travel through time

In the last decades, the use of acoustic emission (AE) method in engineering applications had increased exponentially. AE deals with the analysis of transient elastic waves generated by a sudden release of energy from localized sources within a material. AE technique began in the early 1950's with Joseph Kaiser [1], who was the precursor of this technique in scientific applications. He was the first who used electronic instrumentation to detect audible sounds produced by deformation under tensile test on metallic specimen. The result from his investigation was the observation of an irreversibility phenomenon which is known nowadays as "the Kaiser effect". In the middle of 1950s, Schofield [2] and Tatro [3] improved the instrumentation and clarified the source of AE during plastic deformation. In the decade of 1960s, AE has been applied in the field of material engineering and also as a nondestructive testing (NDT) method in the aerospace industry. It was used by the US Navy to verify the integrity of Polaris rockets motor. In 1963s, Dunegan [4] carried out the first AE test on pressure vessels; extended improvements in instrumentation helped him in the foundation of the first company of AE equipment in the world. In early 1970s, research started on fiber-reinforced composites with the goal of assessing the reliability of AE as a non-destructive test of FRP. Liptai showed the breakdown of "Kaiser effect" in glass fiber reinforced plastic structure. The discovered effect in composite structures is called nowadays "Felicity effect". Ten years later, a committee on AE from reinforced plastics CARP was then established who provided a code (exists under the appellation CARP code). Currently, the range of application of AE is manifold. It varies from the study of the damage process insight material during mechanical behavior investigation on specimen, to the integrity inspection of real structures.

3. Application of AE on composite structures

The acoustic emission technique finds one of its largest application fields in materials research. Examples are various: detection of damage initiation, discrimination between damage mechanisms and their rate evolution under mechanical loading [5,6,7], study of crack propagation under quasi-static [8] and dynamic loading [9]… These applications lead to better understanding the structure / properties relationship. This gave rise to the development of new industrial applications (*i.e.* large structures): pressure vessels, piping, storage tanks, bridges, aircraft, and a variety of other composite components.

AE combined with other methods such as Scanning Electron Microscopy has been proved that it is a promising approach, making results analysis more reliable. Many authors studied this topic and helped the development of a new AE analysis tools. The first AE analysis of the field of composite was performed in the 1971s by Randolph [10]. In 1980s studies were only focused on the damage onset, fracture activity and intensity. The lack of physical background and applicable analysis techniques did not enable the fracture mechanisms discrimination, and only in 1990s that microscopic damage identification has succeeded. Since few years, advances in signal processing and data pattern recognition techniques have given AE signal characterization a renewed interest.

4. Data processing progress to improve continuously the AE reliability

Many studies have shown that identification of damage mechanisms from the AE signals, collected during loading on composite material, is possible using one or more time features, in particular the amplitude signal. See for example Benzeggah and Barre [11], Chen et al. [12], Kim et al [13], Kotsikos et al [14] for further details.

These studies showed that the main damage mechanisms can be ranked in ascending order of AE amplitude signal as following: 1/ matrix cracking, 2/ delamination and debonding, and 3/ fiber fracture. However, these amplitude distributions vary with the type of test (tensile, bending, fatigue, etc.), material properties of the medium of propagation (composition, configuration …). Moreover, in most of these studies, the distribution of amplitude exhibit some overlap area and makes uncertain the association of this amplitude range to a damage mechanisms. For these reasons, other studies focused on simultaneous analysis of multiple parameters to improve the characterization of a given damage. Some authors combine the amplitude to energy [15], others, amplitude to rise time, energy and duration [16, 17]. Furthermore, in the study of Ni and Iwamoto [18], the investigation of the fundamental characteristics of AE signals in the case of a single fiber composite (such as attenuation and frequency dependency),

shows that amplitude distribution can be affected by the distance source-sensor, while the frequencies were almost unchanged. They proved that the frequency analysis is an effective way in processing AE signals of composite materials. These studies were first carried out in the frequency domain using Fast Fourier transform (FFT) and then evolved to time – scale or time-frequency method (Wavelet transform WT). Other authors [19-24] have proven that time-frequency processing method was powerful for identifying the microfailure modes and for elucidating the microfracture mechanisms in composite materials.
For some cases, conventional mono-parametric analysis may be insufficient and proved limited in terms of damage identification (overlapping between AE signals segmentation). In order to remove uncertainties, a multivariate statistical technique, based on pattern recognition methods was used in last decade. The principle is to separate AE signals into k clusters (representative of k damage mechanisms) according to their similarity using pattern recognition algorithms. Each AE signal can be represented by a vector composed of multiple relevant descriptors. In the case of supervised classification, the number of clusters and features may be known. The segmentation algorithms combine the input signals to a cluster from a learning model powered by known damage modes. In contrast, in the case of unsupervised classification, the number of clusters and its features are unknown. These methods use data reduction algorithms and graphical cluster partition analysis. In 1994, improvement of AE analysis using advanced pattern recognition methods were initiated by Ono and Huang [25]. They applied the K-neighbors method for damage identification in carbon and glass fibre composites. In 1995, Anastassopoulos [26], established a failure criterion based on two pattern methods (K-means and max_min). In last years, several studies (Huguet, Godin, marec [5-7]), based on the use of pattern recognition technique, have demonstrated that a reliable AE data identification and a better understanding of damage modes, is possible. The only drawback is that the wide studies focuses on specimens and difficult to be transposed to full-scale structures. This will necessitate further measurement since the single damage pattern could be different (significantly affected by multiple wave propagation effects such as reflections, attenuation, mode conversions or dispersion, sensors-event source distance , dimension, geometry…).

5. Miscellaneous

- Modeling of AE: Modeling of AE propagation waves is possible (some works exist already such as [27]). The main problem in modeling AE is the fact that the source (*i. e.* defect) is unknown, and making some assumptions are needed.
- AE coupled to other techniques: among the limitations of AE, the defect should be progressive (that's to say it should generate a signal when exerting a load on the structure under monitoring). However, in some circumstances, a defect is silent. A combination with a complementary technique is so needed. Mechanical guided waves technique is an example of techniques which can be used for this item [28].
- Modal AE: it's a derivative of AE, and based on exploiting the modal nature of the collected signals. It helps the recognition of the defect occurred. The main problem which should be overwhelmed is identifying the propagation modes of each signal.
- Standards & guidelines: Many standards exist [29, 30]. However, a special care has to be paid when applying these standards.
- Pass/fail criteria: it's a too difficult and important matter despite that AE offers the possibility to exploit many signals features. These criteria change from a structure to another one and depend closely of dimensions, materials, and geometry.
- Famous effects: Kaiser, Felicity, Chelby are key elements in the use via AE.

6. Conclusions

Acoustic emission is applied since longtime on composite structures to improve either quality, design, safety or durability. It is applicable on small as well as large structures. Many codes, standards and guidelines exist to help achieving reliable experiments. However, various kinds of structures are still complex in front of AE, and so many deep investigations are need. One among different examples is the periodic testing of composite overlapped high-pressure vessels. These structures are relatively very thick, which induces a high attenuation of the waves generated by an eventual defect, and increases the number of wave modes. When changing the design pressure and / or the volume, dimensions have to change. Consequently, pass / fail criteria have to be updated. Unfortunately, no numerical models are available today to help updating these criteria and so experiments are always needed, which high costs consuming. This is a simple example, among others, arguing that researches in AE field is always required and inviting, by the way, concerned people (academia and industrial) to invest more and more to resolve problems which are right now complicated.

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References

[1] Kaiser, J., "Untersuchungen uber das auftreten Gerauschhen beim Zugversuuch», PH.D. thesis, Technische hochschule, Munich, 1950.

[2] Schofield, B. H., Bareiss, R. A., "Acoustic emission under applied stress", ASTIA Document AD 155674, WADC Technical report, 58-194, 1958

[3] Tatro, C. A. «Sonic technique in the detection of crystal slip in metal». Engineering Research, Vol.1, pp. 23-28, 1959.

[4] Dunegan, H. L., "Acoustic Emission: A Promising Technique», UCID-4643, Lawrence, 1963.

[5] Huguet, S., « Application de classificateurs aux données d'émission acoustique : identification de la signature acoustique des mécanismes d'endommagement dans les composites à matrice polymère », Thèse de doctorat, Institut National des Sciences Appliquées de Lyon, 2002.

[6] Godin, N, Huguet, S, Gaertner, R., "Integration of the Kohonen's self-organising map and k-means algorithm for the segmentation of the AE data collected during tensile tests on cross-ply composites", NDT&E International 38 (2005) 299–309

[7] Marec, A., Thomas, J.-H., El Guerjouma, R, "Damage characterization of polymer-based composite materials: Multivariable analysis and wavelet transform for clustering acoustic emission data", Mechanical Systems and Signal Processing, Volume 22, Issue 6, pp. 1441-1464, August 2008.

[8] Bourchak, M., Khan A., Badr, S-A., Harasani, W., « Acoustic Emission Characterization of Matrix Damage Initiation in Woven CFRP Composites », Materials Sciences and Applications, 2013.

[9] Okafor, A.C., Singh, N., Singh, N., Oguejiofor, B., «Acoustic emission detection and prediction of fatigue crack propagation in composite patch repairs using neural network ». Journal of Thermoplastic Composite Materials, 2015.

[10] Fitz-Randolph, J., Phillips, D.C., Beaumont, P.W.R., and Tetelman, A.S., «Acoustic emission studies of a boron-epoxy composite», J. Comp. Matls, vol. 5, pp. 542-548. 1971

[11] Barre, S., Benzeggagh, M., «On the use of acoustic emission to investigate damage mechanisms in glass-fiber reinforced polypropylene», Composites Science and Technology, vol.52, pp.369-76, 1994.

[12] Chen, O., Karandikar, P., Takeda, N., Kishi, T., «Acoustic emission characterization of a glass-matrix composite», Nondestructive Testing and Evaluation, vol.8-9, pp.869-878, 1992.

[13] Kim, S.-T., Lee, Y.-T., «Characteristics of damage and fracture process of carbon fiber reinforced plastic under loading-unloading test by using AE method», Materials Science and Engineering, vol.A234-236, pp.322-326, 1997.

[14] Kotsikos, G., Evans, J. T., Gibson, A. G., Hale, J., «Use of acoustic emission to characterize corrosion fatigue damage accumulation in glass fiber reinforced polyester laminates », Polymer Composites, vol. 20(5), pp.689-696, 1999.

[15] Ativitavas, N., Fowler, T., Pothisiri, T., «Acoustic emission characteristics of pultruded fiber reinforced plastics under uniaxial tensile stress», Proc. of European WG on AE, Berlin, pp.447-54, 2004.

[16] Godin, N., Huguet, S. , Gaertner, R and Salmon, L., «Clustering of acoustic emission signals collected during tensile tests on unidirectionnal glass/polyester composites using supervised and unsupervised classifiers». Nondestructive Testing and Evaluation Int, 37:253–64, 2004.

[17] Nechad, H., Helmstetter, A., El Guerjouma, R., and Sornette. D., "Creep ruptures in heterogeneous materials". Physical Review Letters, 94:45501, 2005.

[18] Ni, Q.Q. and Iwamoto, M., "Wavelet transform of acoustic emission signals in failure of model composites". Engineering Fracture Mechanics, 69:717–728, 2004.

[19] Giordano, M., Calabro, A., Esposito, C., D'Amore, A., and Nicolais, L., "An Acoustic Emission Charaterization Of The Failure Modes In Polymer-Composite Materials", Composites Science and Technology, 58, pp.1923–1928, 1998.

[20] De Groot, P. J., Wijnen, P., and Janssen, R., "Real time frequency determination of acoustic emission for different fracture mechanisms in carbon/epoxy composites", Composites Science and Technology, 55:pp.405–412, 1995.

[21] Hamstad, M. A., O'Gallagher, A., and Gary, J., "A wavelet transform applied to acoustic emission signals: part 1: source identification", Journal of acoustic emission, 20:39–61, 2002.

[22] Suzuki, M., Kida, S., Shimbo, M., and Miyano, Y., "Effects of fiber content on fracture mechanisms of short fiber reinforced PET composites", Proc. 8th Int. Conf on Composite Materials, 3, 1991.

[23] Suzuki, M., Nakanishi, H., Iwamoto, M., and Jinen, E., "Application of static fracture mechanisms to fatigue fracture behavior of class A-SMC composite", Proc. 4th Japan-US Conf. on Composite Materials, pages 297–306, 1988.

[24] Piotrkowski, R., Gallego, A., Castro, E., Garcia-hernandez, M. T., and Ruzzante. J. E, "Ti and Cr nitride coating/steel adherence assessed by acoustic emission wavelet analysis", Nondestructive Testing and Evaluation, 38: pp.260–267, 2005.

[25] Ono, K. and Huang, Q., "Pattern recognition analysis of acoustic emission signals", Progress in Acoustic Emission VII, The Japanese Society for NDI, 86:69–78, 1994.

[26] Anastassopoulos A., and Philippidis, T. P., "Clustering methodology for the evaluation of acoustic emission from composites", Journal of Acoustic Emission, 13:11–22, 1995.[27] Ben khalifa, W., Jezzine, K., Grondel, S., Lhémery, A., chatillon, S., "Modeling of the Far-field Acoustic Emission from a Crack under Stress", 30th European Conference on Acoustic Emission Testing & 7th International Conference on Acoustic Emission University of Granada, 12-15 September 2012.
[28] Terrien, N., Dahmene, F., Zejli, H., Habti, M-D, "Structural health monitoring of a smart composite bridge using guided waves and acoustic emission techniques", 7th European Workshop on Structural Health Monitoring, July 8-11, 2014. La Cité, Nantes, France
[29] E2076-05 Standard Test Method for Examination of Fiberglass Reinforced Palstic Fan Baldes Using Acoustic Emission
[30] E1118-05 Standard Practice for Acoustic Emission Examination of Reinforced Thermosetting Resin Pipe (RTRP)