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FAILURE MODES DETECTION IN LAMINATED COMPOSITES

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Abstract: Acoustic emission is a suitable method for real-time health monitoring of composite structures. It should be noted that the identification and classification of failure modes based on acoustic emission is challenging from an engineering practice perspective due to the fact that acoustic emission waves are usually emitted simultaneously from all acoustic emission emitting damage sources. Therefore, advanced signal processing techniques in combination with pattern recognition approaches are required. In this study, fixed sets of acoustic emission signals obtained from laminated carbon fiber reinforced polymer subjected to mechanical deformation testing are analyzed. A new pattern recognition approach is developed, which includes a series of processing steps that can be implemented in real time. Unlike conventional classification approaches, here only the coefficients of the continuous wavelet transform are extracted as relevant features.

Key words: acoustic emission, real-time health monitoring, damage sources, laminated composites, continuous wavelet transform.

High stiffness and strength, good resistance to corrosion and high temperatures of carbon fiber reinforced plastics are the preferred properties from the engineering practice point of view [1]. Unfortunately, however, damage in laminated composites includes a variety of failure modes. Moreover, damage can occur early in the manufacturing process and accumulate over the service life. In recent years, special attention has been paid to the development of reliable and effective online condition monitoring systems capable of detecting and classifying various damage sources. Acoustic emission is considered one of the most suitable non-destructive methods for in situ condition monitoring applications, especially when it is related to dynamic failure investigation [2].

A frequently used method for failure mode identification is the amplitude analysis method. Recorded acoustic emission signals are analyzed in the time domain; the amplitude or energy is considered as a unique parameter describing the failure modes. Each failure mode is associated with a corresponding amplitude. The disadvantage of this method is that the amplitude depends on the fiber orientation, sample geometry, and the location of the radiation detector [3]. As a result, the acoustic emission amplitude is not reported as a meaningful descriptor for damage classification. To overcome this disadvantage, many theoretical and experimental studies have used frequency-based analysis techniques, namely, fast Fourier transform and power spectrum analysis.

Frequency-based analysis shows fewer drawbacks than amplitude-based analysis due to the non-stationary behavior of acoustic emission signals [4]. Time-frequency analysis such as discrete wavelet transforms and continuous wavelet transform is promising for laminated composites flaw detection. Multiple recorded acoustic emission signals allow decomposition into several levels. The rate of change of energy and percentage of total energy of each level were calculated. Each level was assigned to a damage source. Some studies demonstrated the ability of continuous wavelet transform to distinguish acoustic emission signals caused by different failure mechanisms in carbon fiber reinforced polymer. Four different failure modes were identified and correlated. In addition, a correlation was established between failure modes and corresponding frequency ranges. Theoretical analysis highlighted the advantage of wavelet transforms in handling non-stationary signals. For this technique, the continuous wavelet transform was used, which provides suitable time- and frequency-localized information. The acoustic signal information is analyzed simultaneously with high resolution in different frequency ranges. During the last decade, the continuous wavelet transform has been successfully used in the field of acoustic emission analysis and has become one of the most informative analyses, especially because it is also used as a pattern recognition approach. In this paper, a thorough analysis of the waveform and frequency content of acoustic emission signals is performed in order to establish a correlation between the obtained patterns and various failure modes. Theoretical analysis indicates the existence of several deformation modes in laminar composites, which can be reliably identified by acoustic signals. The first signal mode is characterized by the existence of two modes, namely, the tensile mode and the bending mode. The results obtained by applying the continuous wavelet transform show that the high-energy region is located in the high-frequency range. The second mode of signal is associated with the delamination of the laminar composite. And finally, the third mode of signal is characterized by the dominant mechanical tensile mode and the dominant bending mode. The high-energy region shows that the bending mode is the most energetic component with a frequency content in the low-frequency range. Based on the waveform and frequency content, the combination of the first and third mode signals correlates with matrix cracking.

REFERENCES

1. Hegde, S., Shenoy, B. S., & Chethan, K. N. (2019). Review on carbon fiber reinforced polymer (CFRP) and their mechanical performance. Materials Today: Proceedings. Vol. 19. Pp. 658-662. DOI: 10.1016/j.matpr.2019.07.749.

2. Sarasini, F., & Santulli, C. (2014). Non-destructive testing (NDT) of natural fibre composites: acoustic emission technique. Natural fibre composites. Pp. 273-302. Woodhead Publishing. DOI: 10.1533/9780857099228.3.273.

3. Choi, N. S., Woo, S. C., & Rhee, K. Y. (2007). Effects of fiber orientation on the acoustic emission and fracture characteristics of composite laminates. Journal of Materials Science. Vol. 42. Pp. 1162-1168. DOI: 10.1007/s10853-006-1445-1.

4. He, M., Zhang, Z., & Ramakrishnan, K. R. (2018). Delamination identification for FRP composites with emphasis on frequency-based vibration monitoring-a review. Structural Durability & Health Monitoring. Vol. 12(4). P. 213. DOI: 10.32604/sdhm.2018.05122.