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Review on Implementation Parameters of Acoustic Emission towards Crack Detection and Propagation in Adhesive Joints

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ABSTRACT
Acoustic waves have a massive potential in the realm of crack detection. Since cracks remain undetected for a long time, which may result in component damage, all sorts of methodologies which help in crack detection are considered to avoid deterioration and failure. Acoustic Emission (AE) is a critical indicator of crack initiation and propagation. Due to this, crack localization is done effectively using AE in different applications. The methodologies incorporating the acoustic waves' ability to detect and probe the crack existence is found to be practically viable and feasible. The paper makes an effort to analyze the different methodologies incorporating the AE towards the crack detection and propagation from all practical perspectives.

1. Introduction

Adhesive joints are considered in an in-depth manner due to their tremendous potential in replacing traditional joints. Hence the modality of crack detection and propagation in the bond zone needs refinement as the prediction needs to be accurate. AE techniques are found suitable to fulfill this criterion. Hence, the implementation parameters, including the AE equipment, sensors, signals acquired and discrimination, significance, damage mechanisms, need to be reviewed in a detailed manner.

2. The generalized methodology and schematic of AE

The generalized arrangement of implementing an AE system involves the placement of a piezoelectric transducer (AE sensor) on the surface of the affected zone. The transducer can receive the stress accumulation responses generated due to the crack formation and convert them into electric signals (AE signals). The selection of the AE sensors is made based on their frequency of operation. Another modality of AE sensor selection is its sensitiveness. The fundamental arrangement of the AE system involves the AE sensor, a pre-amplifier, a main amplifier provided with the adequate filters, data acquisition software.

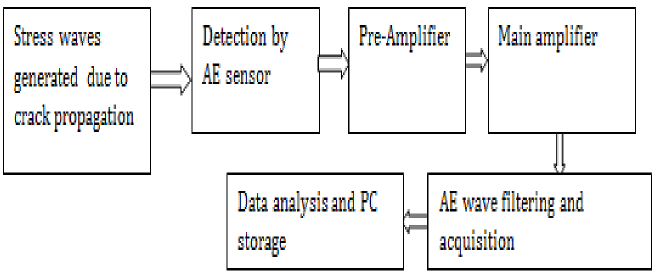

Fig 1. AE system flow diagram

3. Acoustic wave equipment specifications in the realm of crack monitoring

JA Pascoe et al. [1] investigated the crack growth behavior during a single fatigue cycle using AE techniques. The investigation focused on the peak amplitude signal, the rise time, and the energy content measurement. The equipment used was an AMSY-g Vallen 8 channel acoustic emission method with four parametric input channels. The investigation was able to validate that the crack growth took place during both the loading and unloading phases through the AE techniques. As a result of AE techniques, the research was able to successfully analyze the fatigue crack growth behavior during a single fatigue cycle. The AE techniques were able to pinpoint the exact features of a fatigue cycle, which are very crucial for the calculation of the crack growth.

AN Vishvikov et al. [2] undertook a preliminary investigation in the area of crack propagation in a Titanium alloy under fatigue loading. The work witnessed the successful arrangement of an experimental setup, which included an acoustic emission sensor, infrared camera, contact heat flux gauge, and a proper system for crack length monitoring. The experimental data obtained out of this was able to correlate the AE signal energy and the energy dissipation, which was resultant of the plastic deformation. The investigation was able to confirm the different areas possessing intense acoustic activity, which was found to correspond with the various fracture mechanisms under the fatigue crack propagation.

4. AE algorithms

SA Shevchik et al. [3] advocated a new AE algorithm for tracking the crack initiation and propagation inside a medium. The algorithm was innovative due to its potential to recreate the intricate geometry of the crack path. The algorithm was also able to track the crack propagation within the allocated time frame. The results showed that the algorithm was able to provide accuracy in the retrieval of the crack geometrical configuration.

Gutkin et al. [4] analyzed the failure of adhesive joints bonded between CFRP substrates using the AE. Several tests were done for the comparative analysis of the AE signals derived out of them. Specific algorithms like k-means clustering algorithm and SOM algorithm were used for the signal analysis. The combined usage of the algorithms proved to be useful in signal discrimination and analysis.

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V Kostopoulos et al.[5] compared the failure mechanisms derived from the crack propagation using AE data coupled with Unsupervised Pattern Recognition Algorithms. The comparison was crucial in providing excellent insight into the various failure modes as the algorithm effectively classified the AE data derived.

Krampikowska et al. [6] implemented a k-means clustering algorithm for the simulation of various AE activities obtained from various fracture mechanisms. The algorithm had unsupervised pattern recognition modes for the realization of high classification accuracy

D Xu et al. [7] implemented a k-means ++ algorithm, obtained from the k-means algorithm as a foundation for the AE signal discrimination. The algorithm was useful for the segmentation of the AE signal in composite substrate bonded adhesive joints. The algorithm enhanced the clustering, time-domain, and frequency spectrum analyses.

G.Clerc et al. [8] followed a "logarithmic fitting" algorithm for the regular synthesis of mode-2 load in wood substrate bonded adhesive joints. The algorithm was useful for the calculation of the non-linear offset points. This avoided the subjective interpretation of cluster data.

LF Kawashita and SR Hallet[9] implemented a crack tip tracking algorithm, which helped the researchers to track the cohesive element dissemination along the crack front. The algorithm determined the sufficient length and the crack growth rate.

5. AE sensors usage in crack propagation detection

The AE sensors used in crack propagation detection are expected to possess the ability to convert the displacements induced due to AE waves into signals having the collectivity and storable format.

Kral et al. [10] combined the usage of the AE sensors with artificial neural networks(ANN) for measuring the strain wave signals which occur as a result of the crack propagation. The investigation concentrated on the measurement of strain energy released during crack elongation with the help of the AE sensors. The results were further validated using the ANNs. The combinations of the usage of the AE sensors and the ANNs resulted in the formation of a Structural Health Monitoring system in the realm of crack propagation.

The AE sensor, used in the research undertaken by M. Saeedifar et al. [11][12] was a broadband resonant type single-crystal piezoelectric transducer. This sensor had an operating frequency range between 100-900 kHz. An 8 channel AE system having a sampling rate of 2 MHz was used for the successful recording of the AE signals.

Bhuiyan et al. [13] used the Commercial Mistras S9225 acoustic emission sensor and the piezoelectric wafer active sensor for the detection of acoustic emission waveforms generated from the crack propagation. Both the sensors were able to capture the fatigue crack–related acoustic emission waveforms. The piezoelectric wafer sensor showed an enhanced ability towards the detection of frequency information related to crack travel.

6. Researches which provided insight on the AE ability towards signal discrimination

Kietov et al. [14] used AE techniques for detecting the initiation of the crack propagation in nodular cast iron specimens. The AE concentrated on the determination of the local cleavage fracture, which was more sensitive towards AE usage. The investigation was able to correlate the relationship between the amplitude of the AE signals and the size of the cleavage areas. The limitation of this investigation is the confinement of the AE signals towards the local cleavage fracture and not the transition phases from the cleavage zone towards the plastic area.

Maleki et al. [15] used AE techniques for crack monitoring during the analysis of cracked aluminum plates collapse, which was repaired using one composite side patches under fatigue loading. The AE methodology monitored the damage progression, which was likely to be influenced by the repair patches. The investigation established its focus on the discrimination of the AE signals rendered due to both the adhesive layer failure and the aluminum cracking.

Some investigations, including a significant work undertaken by Croccolo et al. [16], focused on the usage of AE as a condition monitoring technique. The AE concentrated on the appraisal of flaw densities in the adhesive layer, which enabled the prediction of the actual failure load of the entire joint. The research was also able to correlate the defect density and the snowballing count of the acoustic emissions. The study successfully predicted the final release moment of the adhesive joint.

7. Researches which were able to relate the AE source with crack propagation parameters

C Barile et al. [17] procured vital statistics about the structural integrity of materials in a sinusoidal fatigue loading scenario using the AE techniques partially along with thermograph techniques. The research was found to validate the ability of the AE to monitor the entire history of failure of the specimens under study. The investigation was also able to correlate the AE signals and the crack propagation phenomenon. The AE provided the flexibility to differentiate between the crack initiation stages from both the stable and unstable crack propagation stages.

M Strantza et al. [18] used the AE technique for monitoring the crack augmentation behavior characteristics of Ti6Al4V specimens, which were subjected to the 4 point bending tests. The investigation focused on the AE signal parameters inclusive of corporate events, hits, standard frequency, and the rise time. These parameters evaluated the correlation between sensitivity and damage, which enabled the researchers to identify the stage just before the ultimate fracture takes place. The novelty of this investigation is the ability to extend the AE techniques to the Additive Manufacturing (AM) components.

Another research undertaken by K Kamiyama et al. [19] concentrated on the AE source locality analysis implemented in an ENF test. The AE was used to establish the relationship between the original crack length and the source of AE creation. This relationship proved very important in the understanding of the entire delamination process in the adhesive joint.

Significant research undertaken by Michalkova et al. [20] concentrated on the progressive crack travel in Double Cantilever Beam(DCB) specimens using AE techniques. Similar to the research referred to in [10], this work was also able to focus on the relationship between the cumulative AE energy and crack growth. The significant mechanical properties of the joint during the separation stages successfully correlated with the AE data. The investigation was able to conclude that the increase in the AE release rate was quite proportional to the crack augmentation induced by fiber rupture.

Another noteworthy investigation done by W Sun et al. [21] concentrated on using AE simultaneously with a video-based assessment. The study concluded that the crack starting and propagation were very much precisely indicated using the AE energy vs. time graph. The investigation made use of a Mistras R151-AST acoustic emission sensor, which operated within the 50 -400 kHz range.

Another investigation done by K Senthil et al. [22] used AE techniques to assist in the detection of fracture toughness in adhesive joints. The study concluded that the AE signals possessed excellent correlation with the load-response behavior, which was very useful in the determination of the crack initiation under mode-2 loading. The signal data generated from the AE techniques was instrumental in the analysis of bond failure behavior in the adhesive joints.

Another research done by Droubi MG et al. [23] highlighted the AE methodology's significance in the identification of time-domain signals spread over the loading phase under mixed-mode load conditions. The AE proved to be very relevant for the prediction of the instance of fracture during the testing. The AE was able to correlate with the adhesive failure to a remarkable level.

Ducept et al.[24] used a mixed-mode bending setup using aluminum and glass/epoxy composites. The research concluded that the cumulative AE signal amplitudes were found to be more near the zone of rupture for adhesively bonded joints. The DCB test specimens generated more AE signals after failure when compared with their ENF counterparts during the uniform load application.

R.Joseph et al. [25] analyzed the utility of the AE signals created due to the rasping of the surfaces, which induce crack faying. The research was done using sheet metal samples subjected to fatigue loading and vibration induction. The research analyzed the nature of the AE signals, which emanated due to this crack faying under the influence of axial static load. The comparison between the signals was made effectively using the Pearson correlation technique. The innovation featured in the research included the creation of an experimental setup that fulfilled the research objective along with the correlations done.

8. Identification of damage mechanisms using AE methods

Chai et al. [26] used AE methodology to analyze different phases during the fatigue of 316LN stainless steel specimens inclusive of ductile crack growth, plastic deformation, and the shear crack growth. The investigation justified the suitability of the AE methodology to study the characteristics of shear crack growth, essential levels of plastic deformation, crack deflections induced due to residual stresses during the crack travel phase.

Fotouhi et al. [27] conducted a failure analysis of an adhesive joint between GFRP substrates using the AE methodology. The research was able to identify four different damage mechanisms, which included adhesive layer failure, fiber rupture, matrix disorientation, and foam hub failure. The AE data was analyzed using the wavelet packet transform method.

EH Saidene et al.[28] undertook research using AE, which assessed various damage mechanisms prevalent in tensile tests conducted on adhesive joints between hybrid-flax glass fiber reinforced composite substrates. The AE methodology successfully coupled with SEM, which was able to analyze the damage mechanism evolution. The research extensively used the AE parameters including cumulative AE energy and number of counts.

De Rosa et al. [29] utilized AE for the analysis of damage dissemination in jute-glass/polyester hybrid laminates. The research related the AE activity to the applied cyclic stress on the joints at different energy levels for the assessment of impact loading and residual stress parameters.

S.Huguet et al.[30] used AE signal parameters for the identification of different damage mechanisms in adhesive joints between GFRP substrates. The data acquisition system made use of a Kohonen self-organizing map, which facilitated the automatic separation of the AE signals, subsequently establishing a correlation with the damage mechanisms. The results derived from the investigation concluded that the different peak amplitude, signal duration, and energy distributions represented the matrix cracking and decohesion.

Godin et al.[31]used AE based on the principal component analysis (PCA) using a *k*-means algorithm, which enabled the classification of AE data collected from the tensile tests done on unidirectional glass-fiber composites. The research was able to identify four different types of damage mechanisms, namely matrix cracking, matrix debonding, fiber breakage, and total delamination.

9. Conclusion

A review was done to establish the implementation parameters of the AE methodology towards crack detection and propagation. Some points have emerged, enabling the effectiveness of AE implementation.

1. The AE signals acquired in the majority of the researches were discriminated using C means algorithm, which successfully correlated with the crack propagation data.
2. The AE was able to provide clarity in the analysis of the damage mechanisms which decided the delamination sequence between the different substrates used in the researches reviewed.
3. Several researchers compared the experimental data results of the tensile tests with that of the AE and revealed the accuracy of the results, which provided insights on the crack propagation nature.

Hence, the review provided the foundation stone for implementing the AE towards the analysis of crack propagation between dissimilar substrates.

References

[1] Pascoe JA, Zarouchas DS, Alderliesten RC, Benedictus R, 'Using acoustic emission to understand fatigue crack growth within a single load cycle,' [2018], Engineering Fracture Mechanics, vol (194), pp. 281-300.

[2] Vishvikov AN, Iziumova AY, Panteleev IA, Ilinykh AV, Wildemann VE, Plekhov OA, ' The study of a fatigue crack propagation in titanium Grade 2 using analysis of energy dissipation and acoustic emission data', [2018], Engineering Fracture Mechanics, In press, Corrected proof.

[3]Shevchik SA, Meylan B, Violakis B, Wasmer K, '3D reconstruction of cracks propagation in mechanical workpieces analysing non-stationary acoustic mixtures', [2019], vol(119), pp.55-64.

[4]Gutkin R, Green CJ, Vangrattanachai S, Pinho ST, Robinson P, Curtis PT, 'On acoustic emission for failure investigation in CFRP: Pattern recognition and peak frequency analyses', (2011), Mechanical Systems and Signal Processesing, Vol.25, pp. 1393-1407.

[5] Kostopoulos V, Loutas T, Dassios K, ‘ Fracture behavior and damage mechanisms identification of SiC/glass ceramic composites using AE monitoring’, (2007), Composites Science and Technology, Vol.67, pp.1740-1746.

[6] Krampikowska A, Pala R, Dzioba I, Swit G, ‘The use of the Acoustic Emission Method to identify Crack Growth in 40CrMo Steel’, (2019), Materials, Vol 12(13), pp.2140-2147.

[7] Xu D, Liu PF, Li JG, Chen ZP, ' Damage mode identification of adhesive composite joints under hygrothermal environment using acoustic emission and machine learning,' (2019), Composite structures, vol (211), pp.351-363.

[8] Clerc G, Brunner AJ, Josset S, Niemz P, Pichelin F, ' Adhesive wood joints under quasi-static and cyclic fatigue fracture Mode II loads,' (2019), International Journal of Fatigue, vol(123), pp.40-52.

[9] Kawashita LF, Hallet SR, ' A crack tip tracking algorithm for cohesive interface element analysis of fatigue delamination propagation in composite materials' (2019). International Journal of Solids and Structures, vol(49), pp.2898-2913.

[10]Kral Z, Horn W, Steck J, ' Crack Propagation Analysis Using Acoustic Emission Sensors for Structural Health Monitoring Systems', [2013], The Scientific World Journal, vol. 2013, Article ID 823603.

[11] Saeedifar M, Fotouhi M, , Sadeghi S, Ahmadi Najafabadi M, Minak G. "Investigation of the damage mechanisms for mode I delamination growth in foam core sandwich composites using acoustic emission", (2015), Structural Health Monitoring, vol 14(3), pp.265-280.

[12] Saeedifar M, Maleki A, Najafabadi MA, Zarouchas D, 'The fatigue failure study of repaired aluminium plates by composite patches using Acoustic Emission', [2019], vol(210), pp.300-311.

[13] Md Yeasin Bhuiyan, Bin Lin and Victor Giurgiutiu ‘Acoustic emission sensor effect and waveform evolution during fatigue crack growth in thin metallic plate’, (2018), Journal of Intelligent Material Systems and Structures , Vol. 29(7), pp. 1275–1284.

[14]Kietov V, Henschel S, Kruger L, ' Study of dynamic crack formation in nodular cast iron using the acoustic emission technique', [2018], Engineering Fracture Mechanics, vol 188, pp.58-69.

[15] Maleki A, Saeedifar M, Najafabadi MA, Zarouchas D, 'The fatigue failure study of repaired aluminium plates by composite patches using Acoustic Emission', [2019], vol(210), pp.300-311.

[16] Croccolo D, Cuppini R. 'Adhesive defect density estimation using the acoustic emission technique', International Journal of Adhesion and Adhesives, [2009], vol(29), pp.234–239.

[17] Barile C, Casavola C, Pappalettera G, Pappalettere C, ' Analysis of crack propagation in stainless steel by comparing acoustic emissions and infrared thermography data', [2016], Engineering Failure Analysis, vol 69, pp. 35–42.

[18]Strantza M, Hemelrijck DV, Guillaume P, Aggelis DG, ' Acoustic emission monitoring of crack propagation in additively manufactured and conventional titanium components', [2017], Mechanics Research Communications, vol84, pp.8-13.

[19] Kamiyama K, Mikuni M, Matsumoto T, ' Fracture propagation analysis on two-component type acrylic adhesive joints', [2018], vol(83), pp.76-86.

[20] Michalkova L, Kadlec M, ' Carbon/epoxy composite delamination analysis by acoustic emission method under various environmental conditions', [2016], vol(69), pp.88-96.

[21] Sun W, Sebastian W, Keller T, Ross J, ' Mixed-mode fracture properties of GFRP-adhesive interfaces based on video gauge and acoustic emission measurements from specimens with adherend fibres normal to the interfaces', [2017], Composites Part B: Engineering, vol(123), pp.179-192.

[22] Senthil K, Arockiarajan A, Palaninathan R, 'Experimental determination of fracture toughness for adhesively bonded composite joints', [2016], Engineering Fracture Mechanics, vol 154, pp.24-42.

[23] Droubi MG, Macafee J, Horne RC, Walker S, Klaasen C, Crawford A, Prathuru AK, Faisal NH, ‘Mixed-mode fracture characteristics of metal to metal adhesively bonded joints: experimental and simulation methods”, [2017],. Procedia Structural Integrity, vol 5, pp. 40-47.

[24] Ducept F, Davies P, Gamby E, ‘Mixed mode failure criteria for a glass/epoxy composite and an adhesively bonded composite/composite joint’, International Journal of Adhesion and Adhesives, [2009], vol(20), pp.233–244.

[25] Joseph R, Bhuiyan Y, Giurgiutiu V, 'Acoustic emission from vibration of cracked sheet-metal samples,' Engineering Fracture Mechanics 217 (2019) 106544.

[26] Chai M, Zhang J, Zhang Z, Duan Q, Cheng G, 'Acoustic emission studies for characterisation of fatigue crack growth in 316LN stainless steel and welds', [2017], Applied Acoustics, vol(126), pp.101-113.

[27] Fotouhi M, Saeedifar M, Sadeghi S, Ahmadi Najafabadi M, Minak G. "Investigation of the damage mechanisms for mode I delamination growth in foam core sandwich composites using acoustic emission", (2015), Structural Health Monitoring, vol 14(3), pp.265-280.

[28] Saidene EH , Scida D, Assarar M, Ayad R. 'Damage mechanisms assessment of hybrid flax-glass fibre composites using acoustic emission', (2017), Composite Structures, vol(174), pp. 1–11.

[29] De Rosa IM, Santulli C, Sarasini F, Valente M. 'Effect of loading-unloading cycles on impact-damaged jute/glass hybrid laminates', (2009), Polymer Composites, vol 30(12), pp.1879–87.

[30] Huguet S, Godin N, Gaertner R, Salmon L, Villard D. 'Use of acoustic emission to identify damage modes in glass fibrereinforced polyester', (2002), Composites Science and Technology, vol 62, pp. 1433–1444.

[31] Godin N, Huguet S, Gaertner R, Salmon L. 'Clustering of acoustic emission signals collected during tensile tests on unidirectional glass/polyester composite using supervised and unsupervised classifiers', (2004), NDT & E International Vol 37(4), pp. 253-264.