A Critical Review of the Role of Acoustic Emission Algorithms in the Delamination Analysis of Adhesive Joints

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Abstract - *Acoustic Emission (AE) algorithms are known for their novelty in deciphering the complications involved in delamination sequence analysis, which are crucial in substantiating the joint validation. The suitability of the algorithms lies in the methodology establishment of inducing the received AE signal clarity during the AE tests. The confusions created in the signal clustering are readily eradicated using the algorithm implementation in the AE application. Hence, it is very significant that an orderly review needs to be done on the AE algorithm implementation process which will definitely provide clarity and insight in the methodology establishment of delamination prediction. The paper precisely attempts to review a few algorithms which are used extensively in AE application in the delamination analysis of Adhesive joints.*

Key Words: Acoustic Emission (AE), Self Organising Map (SOM)

1. INTRODUCTION

Adhesive joints are considered in an for their remarkable potential in the replacement of conventional joints. Hence the modality of delamination in the bond zone needs refinement as the prediction needs to be precise in joint validation. The AE methodology is found to suitably fulfill this criterion. The role of an AE algorithm implementation is very important for ensuring the effectiveness of the AE methodology. The clarity in the implementation sequence of the algorithms will remove the complications in decluttering the AE signals. Hence the paper endeavors to analyze a few algorithms which have a prominent place of existence in a wide range of research works done in the delamination analysis of the adhesive joints.

2. THE GENERALIZED METHODOLOGY AND SCHEMATIC OF AE ALGORITHM

The AE algorithms are usually deployed to decipher significant AE parameters which include the amplitude, duration timing, counts, rise time, reliable energy, average frequency, and the peak frequency[1]. A generalized flow chart that aptly depicts the AE algorithm's suitability for the delamination analysis, is listed in fig 1.

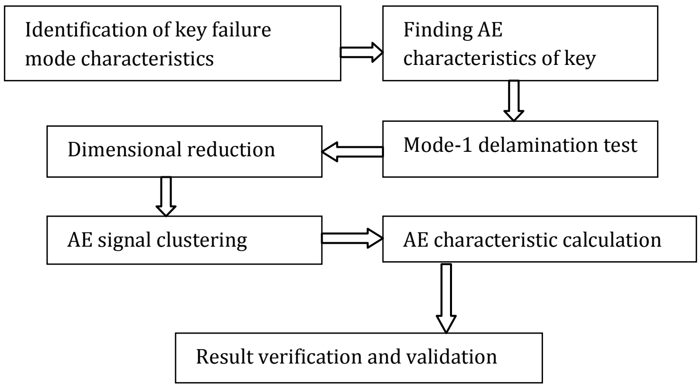

Fig -1: Generalised flow chart for AE algorithm implementation

3. K-MEANS ALGORITHM

The k-means algorithm possesses the ability to incorporate clustering techniques and artificial neural networks in the most optimal manner.

R Gutkin et al. [2] investigated the failure in CFRP substrate joints using AE. Different tests inclusive of Double Cantilever Beam (DCB), four-point bend End notched Flexure (4-ENF), Compact Tension (CT), and Compact Compression (CC) were done for comparative analysis of the AE signals derived out of them. Specific algorithms like k-means clustering algorithm, algorithms which combined k-means clustering with other techniques, and algorithms incorporating Competitive Neural Networks(CNN) were used for the signal analysis. The combination algorithms proved to be useful in signal discrimination and analysis.

Krampikowska et al.[3] used a k-means clustering algorithm for the characterization of various AE activities derived from various fracture mechanisms. The algorithm used unsupervised pattern recognition modalities for the realization of high classification accuracy

D Xu et al. [4] used a k-means ++ algorithm, which was derived from having the k-means algorithm as a base for the clustering of AE signals. The algorithm was found to be very useful in AE signal discrimination in adhesive joints between composite substrates. The selected algorithm enhanced the different analyses, which included clustering, time-domain, and frequency spectrum.

Zhou et al. [5] used the k-means algorithm for precisely distinguishing the damage mechanisms using principal component analysis. The AE signals included RA value, peak frequency, and amplitude. The damage mechanisms included matrix cracking, debonding, delamination, and fiber breakage. The selected algorithm used cluster analysis for the determination of the characteristic frequency of each mode.

Pashmforoush et al. [6] used a combination of the k-means algorithm and the genetic algorithm for the classification of damage mechanisms during mode-1 delamination analysis. The integration of the two algorithms proved to instrumental for numerical data set clustering. Also the dimensionality of redundant data was significantly minimized.

Tabrizi et al. [7] used the K-means algorithm for the classification of the damage mechanisms in the bonded zone of the adhesive joints formed between glass/carbon fiber composite substrates.

Yilmaz et al. [8] were able to use the K-means algorithm for useful acoustic data clustering in adhesive joints formed between GFRP substrates. The algorithm was able to reveal the relativity between the material properties and matrix cracking during the delamination sequences.

4. UNSUPERVISED PATTERN RECOGNITION AE ALGORITHMS

Many types of research involving AE implementation towards delamination relies on pattern recognition algorithms because they can successfully differentiate the complex cluster data and relate them with the different failure modes.

V Kostopoulos et al.[9] correlated the damage mechanisms resultant of crack propagation using AE data coupled with Unsupervised Pattern Recognition Algorithms. The correlation was instrumental in providing valuable insights into the various failure modes as the algorithm effectively classified the AE data derived.

Moevus et al. [10] used an unsupervised pattern recognition algorithm for discrimination of AE signals derived from tests done on SiCf composite substrate joints. The algorithm proved to be very helpful for the identification of different stages of matrix cracking.

5. KOHONEN SOM AE ALGORITHM

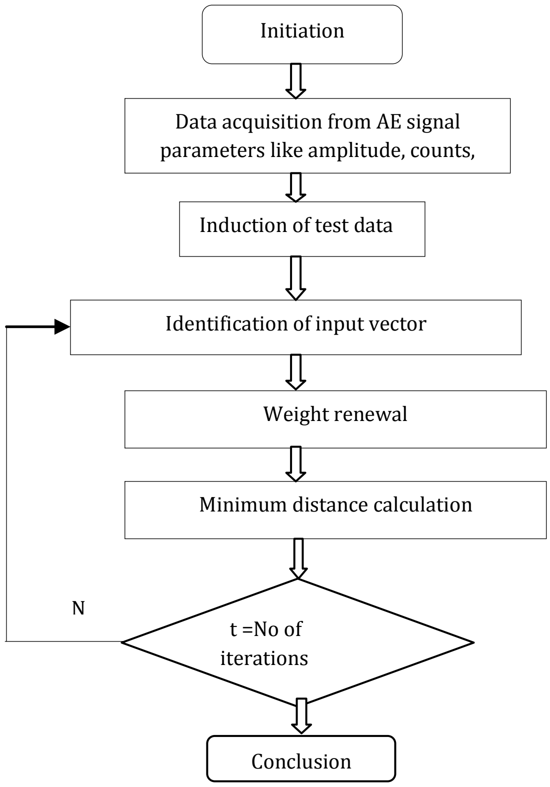

Fig -2: Flow chart for the Kohonen SOM

Fig 2 illustrates the generalized implementation sequence of the Kohonen SOM in AE methodologies towards delamination analysis.

Huguet et al. [11] used the Kohonen SOM AE algorithm for the identification of AE signal parameters for the identification and characterization of various damage mechanisms in stressed glass fiber reinforced polymer composites. The data from the acoustic emission were used as inputs in the mentioned algorithm which which automatically separated the acoustic emission signals, enabling a correlation with the failure mode. The results proved to render valuable perspectives in the realm of real-time damage recognition in complex composite materials.

Oliveira and Marques [12] also used the same Kohonen SOM for damage identification and discrimination of composite materials. The algorithm was based on the AE signal clustering using artificial neural networks. An unsupervised methodology based on the algorithm was developed and applied to a cross-ply glass-fiber/polyester laminate, which was subjected to a tensile test. Altogether, six different AE waveforms were identified.

Fallahi et al. [13] used the Kohonen SOM for the successful clustering of AE signals by the responsible fracture mode. This enabled the research to successfully recognize and detect various damage mechanisms that were responsible for the failure of adhesive joints formed between carbon and epoxy substrates. The algorithm was able to successfully detect the AE parameters which included Rise Time, Counts, amplitude, duration and energy.

Bousetta et al[14] used the Kohonen SOM for the successful analysis of the delamination of joints formed between glass and polyester filament wound composite substrates. The AE signals derived from tensile tests were discriminated which provided insight on the responsible damage mechanisms. The analysis was furthermore augmented using microscopic studies of the damaged zones.

6. OTHER TYPES OF AE ALGORITHMS

SA Shevchik et al. [15] devised and proposed a new AE algorithm for tracking both crack initiation and propagation inside a medium. The algorithm proved to be innovative due to its ability to recreate the complex geometry of the crack path and also its ability to track the crack propagation within the stipulated time frame. The results indicated that the algorithm was able to exhibit high efficiency in the retrieval of the crack geometrical configuration.

G.Clerc et al. [16] used a "logarithmic fitting" algorithm for the automatic synthesis of mode-2 load in adhesive joints between wood substrates. The algorithm was very instrumental for the calculation of the non-linear offset points, which avoided subjective interpretation of cluster data. The algorithm followed the raw data structure.

LF Kawashita and SR Hallet[17] devised a crack tip tracking algorithm, which enabled the exact estimation of the cohesive element propagation along the crack front. The algorithm was beneficial as it automatically determined the sufficient length and the crack growth rate.

Ciampa and Meo [18] developed an algorithm that used the distinctions from the stress waves procured from piezoelectric sensors, which were surface bonded. The algorithm used was not dependent on the thickness and lay-up of the joint and also the anisotropy group velocity of the AE waveforms.

Kurokawa et al. [19] formulated an algorithm for impact position founded on elliptical group-velocity delineate. The algorithm was found to be ideal for quasi-isotropic and unidirectional composite substrate joints.

Kundu et al. [20] devised an optimization AE algorithm that was used to determine the point of impact on aluminum and composite substrates. The algorithm minimized error functions used for predicting the difference in arrival times of AE signals.

CONCLUSIONS

A review was undertaken to analyze the scope of the AE algorithms in the AE implementation methodologies conducive for delamination analysis in an adhesive joint. Some essential points emerged which were considered to be very crucial for algorithm selection.

1. The k-means algorithm and the Kohonen SOM algorithm were found to be more prominent in the choice of AE algorithm as they specialize in unsupervised pattern recognition when compared with other algorithms.
2. Both the algorithms mentioned were able to precisely detect the AE parameters, which included Rise Time, Counts, amplitude, duration and energy.
3. The other algorithms were more specific in the areas of providing insight in the areas of real-time damage recognition in joints bonded between composite substrates.

The review was done as a stepping stone for a very critical analysis, which was done on a mode-1 DCB test [21], which involved dissimilar substrates. Since dissimilarity is found to influence delamination, the need for the implementation of AE methodology emerged. Hence, the review on AE algorithm was done which proved to be very useful in AE signal discrimination during the delamination sequences.

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