ABSTRACT

In aerospace and automobile applications, various composite parts are required to be joined together using either adhesives or mechanical fasteners. One of the aims of this research work is to discriminate the failure modes on lap joints of glass-fiber reinforced plastic (GFRP) and basalt-fiber reinforced plastic (BFRP) laminates and the role of composite structural design in the joint strength. To design structural components, a deep understanding about material behavior and its failure mechanisms is necessary. Characterization of failure modes in the case of composite lap joints is a complex research subject. Hence, the present study is focused on acoustic emission (AE) characterization of failure modes in three prominent joining methods, namely, bonded, riveted and hybrid joints.

The aim of this research work is to identify the associated failure modes during tensile tests of composite lap joints using AE signals. The AE data acquired during the tensile test has been analyzed using different techniques viz: (1) parametric studies (failure discrimination based on the AE parameters), (2) fast Fourier transform (FFT) (individual peak frequency content of each failure modes), (3) continuous wavelet transform (CWT) (time information and frequency range for failure modes), (4) finite element analysis (FEA) (Von Mises stress distribution), and (5) scanning electron microscope (SEM) (possible failure modes using microscopic observation of fractured surface). The proposed methods are applied to identify the dominant peak frequency ranges for each lap joint under tensile loading.

Parametric analysis as a first approach is performed using AE count rate, cumulative counts, time, frequency, amplitude and duration on the AE
data obtained during the tensile testing of lap joints. As AE amplitude parameter suffers from attenuation after preliminary investigations in the parametric analysis, the failure modes are characterized mostly using frequency analysis.

The second approach is based on the extraction of frequency content from AE waveform with appropriate algorithms. FFT analysis is performed on a number of randomly chosen waveform pertaining to different frequency ranges to identify the frequency content of each failure mode. The failure modes such as adhesive failure, light fiber tear failure and fiber tear failure are identified separately from pure resin, single layer and double layer specimens in adhesive-bonded lap joints. The failure modes of fractured surface are observed using SEM for single and double lap joint specimens.

The third approach that is based on the sequence of failure events and their associated frequency content is studied by performing peak frequency on the selected AE signals. The range of peak frequency with time pertaining to the failure modes on lap joints, namely, bonded, riveted and hybrid joints, have been identified using wavelet transform (WT) analysis. Signals and their characteristics representing different failure modes are identified using WT analysis and verified with FFT analysis.

The capabilities of the AE technique used to monitor the failure modes and ultimate strength of lap joint specimen during tensile loading related to the amount of AE activities obtained for the given loading conditions. The plot of AE count rate and AE cumulative counts versus displacement serves as a better tool for studies pertaining to the onset of failure. The hits with higher AE counts are found during the initial stages of loading for failure of lap joint specimens.
In the glass/epoxy laminate, frequency analyses of the AE data were obtained during the tensile testing of single lap bonded, riveted and hybrid joints. It revealed that there were four ranges of frequency content such as 80–100 kHz corresponding to adhesive failure, 110–150 kHz corresponding to shear failure, 110–200 kHz corresponding to light fiber tear failure and 200–270 kHz corresponding to fiber tear failure. The range of peak frequency pertaining to the above failure modes were obtained by using AE monitoring from different single and double lap joints during the tensile tests. In the basalt/epoxy laminate, the relevant frequency ranges were 80–100 kHz corresponding to adhesive failure, 110–150 kHz to shear failure and 110–200 kHz corresponding to light-fiber tear failure. Apart from these failure modes, high frequency ranges, that is, fiber tear failure mode between 200 kHz and 300 kHz in adhesive-bonded and hybrid lap joints of basalt laminate requires more attention. In the case of double lap joints, the relevant frequency ranges were 80–100 kHz corresponding to adhesive failure, 110–200 kHz corresponding to mixed failure modes and 200–270 kHz corresponding to fiber tear failure. It was observed that the peak frequency content of the three possible failure modes were further verified with the results obtained from single lap joints such as glass/epoxy specimens and basalt/epoxy specimens. It was observed that the Young’s modulus of the GFRPs is equivalent to Young’s modulus of the BFRPs. Hence, same frequency ranges are identified for lap joints of GFRP and BFRP laminates using AE monitoring. Moreover, it was also observed that basalt fiber/epoxy might be used as a replacement for glass fiber/epoxy, especially in the area of composite bonded lap joints.

However, noise signals appearing along with the source signals may present a limitation for frequency analysis, as the fixed frequencies of the
different failure modes may also contain noise. These problems can be addressed by using discrete wavelet transform (DWT) to the noise in the signals without affecting the primary frequency content of the signal. The main feature of wavelet transform analysis is to extract information from the original signal by decomposing it into a series of approximations (lower frequency) and details (higher frequency) distributed over different frequency bandwidths. CWT and DWT analysis are used to determine the most energetic levels of decomposition and then identify the frequency bands representative of different failure modes.

From FEA results, it is seen that the initial failure occurred at the overlap edge of lap joints when the equivalent stress reached the ultimate stress of the adhesive. FEA software used to predict the initial failure and crack initiate at the edge of the overlap region based on the Von Mises stress distributions.

FFT and WT analysis of the AE signals are useful tools in the identification of peak frequency ranges for discrimination of failure modes. It was observed that the strength of the lap joints of BFRP laminates is better than lap joints made of glass fiber/epoxy specimens. This is due to the higher interfacial bonding strength of basalt fiber/epoxy specimens compared to glass fiber/epoxy specimens. It is suggested that the application of basalt/epoxy laminate as a strengthening material is useful for joining of composite structural members.