

RESEARCH INTERESTS

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1. Ultimate Strength Prediction from Low Level Proof Loads

Both statistical and backpropagation neural network (BPNN) techniques for predicting burst pressures in filament wound composite pressure vessels have been developed using acoustic emission (AE) data taken at low hydrostatic proof loads. These analyses included undamaged [1] and impact damaged [2] bottles, both propellant filled (simulating rocket motor cases) and unfilled, as well as some containing manufacturing defects [3-5]. Predictions were successfully made in 5.75 inch diameter graphite- [1], Kevlar®- [2], and fiberglass-epoxy [3-5] pressure vessels plus 18 inch diameter graphite-epoxy [3] vessels. The same techniques were employed in predicting burst pressures in undamaged, impact damaged, and cut hoop fiber damaged 15 inch diameter graphite-epoxy overwrapped aluminum pressure vessels at ambient and cryogenic temperatures [6]. The effects of size, material, temperature, and damage state were all accounted for in the statistical and neural network analyses. Burst pressure predictions in every case were obtained with a worst case error within $\pm 5\%$. Thus, a technique has been developed to accurately predict burst pressures in filament wound composite pressure vessels using AE flaw growth data generated at the beginning ($\leq 25\% P_{burst}$) of the hydrostatic pressurization cycle.

This technique has also been applied to the prediction of ultimate strengths in graphite-epoxy tensile test specimens [7], fiberglass-epoxy I-beams in cantilever loading [8], and rectangular cross-section fiberglass-epoxy beams in three-point bending [9]. Moreover, it has been used to predict ultimate compressive loads in impact damaged fiberglass-epoxy coupons [10,11], and finally, it has been employed to predict ultimate strengths in 2195 aluminum-lithium welds [12]. Hence, this method for predicting failure strengths from low proof load AE flaw growth data in composites can be applied to metal structures as well. Study of the underlying mathematics should lead to the development of a microscopic failure theory for real world structures.

2. Fatigue Life Prediction

In a technique similar to that used for predicting burst pressures and ultimate strengths, the fatigue lives of inconel and stainless steel aerospace bellows were predicted with a worst case error within $\pm 5\%$ from AE flaw growth data taken during the first 10% of life [13]. Again this was accomplished through the use of both BPNNs and multivariate statistical analysis. More recently this technique was effectively applied to the prediction of the fatigue lives in notched 7075-T6 aluminum fatigue specimens undergoing three sets of low cycle fatigue loadings: 0-4,000, 0-3,000, and 0-2,000 lb_f ($R = 0.0$) [14-16]. Multiple hit data (noise) and sparse data sets (< 250 hits) led to worst case errors of 16.4% and -13.9% for the first two loading conditions; however, the 0-2,000 lb_f cyclic loading had results similar to the bellows, a 3.66% worst case prediction error. For this last loading condition the AE data used for prediction were taken during the first 25% of the average cyclic life of the notched specimens. It is expected that this technique will also work in predicting fatigue lives in composites.

3. In-Flight Fatigue Crack Growth Monitoring in Aircraft

Fatigue crack growth, rivet fretting, and rubbing noises in aluminum aircraft structures have been classified from AE data using Kohonen self-organizing map (SOM) neural networks. Similar results were obtained from the power spectra of the raw AE waveforms [17,18] and from the six AE waveform quantification parameters [19]: counts, energy, amplitude, duration, risetime, and counts-to-peak. In-flight fatigue crack monitoring systems have been successfully flown on the engine cowling of a Piper PA-28 Cadet [20] and on the vertical tail of a Cessna T-303 Crusader aircraft [21]. Such systems can be used to promote maintenance schemes based on *replacement for cause* rather than replacement at conservatively calculated intervals using fracture mechanics. This research should help minimize maintenance costs and extend the service lives of aging aircraft.

4. Classification and Modeling of Failure Mechanism Data

Classification and modeling of acoustic emission flaw growth data is important in the prediction of failure stresses/loads in both metal [12] and composite [3,4] structures. Knowing the percentages of the various failure mechanisms has allowed the development of ultimate strength prediction equations. However, in order for the prediction to be accurate, the failure mode classification must be correct [22,23], which requires SOM neural networks [24,25] plus mathematical modeling to eliminate outliers [26]. This research has shown that the six AE waveform quantification parameter distributions – counts, energy, amplitude, duration, risetime, and counts-to-peak – can best be modeled by either lognormal [25] or bounded Johnson [26] distributions, the latter being more accurate.

5. Source-Receiver Problem

The source-receiver problem in acoustic emission nondestructive evaluation involves determining the waveform source from the transducer output of a received signal that has propagated through an elastic medium. Identifying the source involves a deconvolution in three parts: the transducer response, the specimen response, and the transducer-specimen interface response. A reciprocity technique for calibrating piezoelectric transducers in a diffuse field was developed [27], which represents the transducer response portion of the source-receiver problem. Exact normal mode solutions for the forced vibrational response of the rectangular parallelepiped (block) with uniformly-loaded and stress-free boundary conditions have also been obtained for the specimen response portion of the source-receiver problem. These solutions include rigid, rigid-lubricated [28], mixed [29], stress-free [30], and uniformly-loaded [31] boundary conditions. Knowing the transducer output and the transducer and specimen responses allows the solution of the transducer-specimen interface response. The next step in this research is to verify these solutions using experimental and computational techniques. Once verified, the solutions for the real world problem of an unknown source with an unknown location in a given three-dimensional structure will have been obtained.

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