Matrix Cracking Onset Stress as a Function of Temperature in SiC\textsubscript{f}/SiC Ceramic Matrix Composites via Acoustic Emission

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1. Abstract

Ceramic Matrix Composites (CMCs) are a key material in the design of next-generation gas turbine engines. Due to their superior thermal and mechanical properties, CMCs may replace metals in components such as vanes and blades. Under mechanical stress, the initial phase of damage accumulation in these materials is initiation and propagation of cracks in the matrix phase. Acoustic emission (AE) has been used in laboratory experiments on SiC/SiC CMC coupons to detect this damage, and establish an AE onset stress value for the material at a range of temperatures. Unsupervised pattern recognition (UPR) in the form of k-means clustering was used in efforts to link different AE signal characteristics to specific damage mechanisms. The analysis revealed that true matrix cracking onset stress may be lower than traditional techniques suggest.

2. Material and Experimental Details

CMC panels were in the form of 0/90° reinforcing fibres, and matrix phase added via CVI SiC and Si silicon processes. From this, dog bone specimens were extracted with gauge length measuring nominally 40 x 10 x 5mm. Uniaxial monotonic tensile tests were performed to failure under displacement control at a rate of 0.5mm/min. A two-zone split furnace was used to heat the specimen to a maximum of 1100°C, monitored with type N thermocouples. Strain was measured with a 25mm extensometer.

AE was sampled at 5MHz via two wideband sensors positioned at either end of the gauge. A time-of-flight location algorithm was used to reject events that did not originate within this region of interest. At elevated temperatures, waveguides were used to transmit AE from the specimen to the sensor. At room temperature, sensors could be attached directly to the specimen surface, although some RT tests utilised waveguides for consistency. Improved UPR results were obtained when sensors were attached directly to the specimen.

3. Results I

A total of 23 tests were performed, including three repeats at each temperature, and further repeats at temperatures where unexpected scatter was observed in the data. The onset stress was calculated using the ‘linear intercept’ method \cite{1}, in which a straight line is traced through the gradient of the linear portion of the cumulative AE energy curve back to the x-axis intercept.

The complete set of results is plotted in the figure below. In general, the AE onset stress was reasonably consistent at all temperatures. It could be interpreted that the trend increases slightly between 200–800°C, but all results at elevated temperatures fall within the scatter of the repeats at RT.

\begin{center}
\begin{figure}
\centering
\includegraphics[width=0.5\textwidth]{figure1.png}
\caption{AE Onset Stress (Linear Intercept) as a Function of Temperature}
\end{figure}
\end{center}

4. Results II

One ultimate objective of the research is to associate specific damage modes in the CMC with the corresponding AE signal characteristics. To this end, AE from RT tests (in which the sensors were attached directly to the specimen surface) was post-processed using a k-means clustering algorithm. Four clusters were sought (chosen to correspond roughly with the number of damage modes anticipated), with random initial partitioning, and the algorithm was run multiple times to ensure a consistent result.

The UPR results suggested that certain clusters of signals could be associated with specific damage modes:

- **Cluster 0**: Accumulated the majority of its energy during the proportional region of the stress curve, which is traditionally dominated by matrix cracking. Signals were typically very low in amplitude and energy.
- **Cluster 1**: Active immediately following the proportional limit and almost entirely ceased well in advance of failure. Correlates with the debonding/sliding region.
- **Cluster 2**: Similar to cluster 1, one order of magnitude greater in energy.
- **Cluster 3**: Active throughout the test, difficult to associate with a specific damage mode. Represented the highest energy signals (total energy in cluster 3 was three orders of magnitude greater than cluster 1).

Importantly, if the linear intercept method of onset stress was applied only to cluster 0, the true ‘matrix cracking’ onset stress was significantly lower than indicated by the previous results.

5. Conclusions

- There is little variation in the AE onset stress at temperatures between RT and 1100°C
- UPR has been used to identify clusters of AE signals linked to matrix cracking and interfacial debonding/sliding. Fibre failures remain difficult to identify.
- The AE linked to matrix cracking initiates at significantly lower stresses than the traditional onset stress indicated by the full cumulative AE energy curve.