Acoustic Emission of Various Woven C/SiC Composites Tested in Tension at Room Temperature

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Modal acoustic emission (AE) has proven to be an excellent technique to monitor damage accumulation in ceramic matrix composites. In this study, AE was used to monitor tensile load-unload-reload hysteresis tests for a variety of C fiber reinforced, SiC matrix composites. C/SiC composites were reinforced with T-300 and IM7 fibers, had C, multilayer, or pseudo-porous C interphases, and had chemical vapor infiltrated SiC or melt-infiltrated SiC matrices. All of the composites exhibited considerable AE during testing. The extent and nature of the AE activity will be analyzed and discussed in light of matrix cracking and the variety of composite constituents. It is hoped that understanding the nature of stress-dependent damage accumulation in these materials can be of use in life-modeling for these types of composites.

Acoustic Emission and Damage Accumulation for Various Woven C/SiC Composites Tested in Tension at Room Temperature

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Objective

Determine and compare acoustic emission (AE) activity of different C/SiC composites tested in tension with transverse cracking

This will serve as a basis for the understanding and comparison of future:

1. Developmental C/SiC composites and other composite systems, e.g., SiC/SiC
2. Fatigue and rupture tests of C/SiC materials

Procedure

- Perform room temperature unload-reload tensile hysteresis tests on C/SiC matrix composites
  - Monitor modal AE* (i.e., digitized waveforms) during the test
- Polish sections of untested material and failed specimens to determine transverse crack density before and after testing
- Compare AE results with damage accumulation for six different C/SiC composites

*** Digital Wave Corp. (Englewood, CO) *Fracture Wave Detector*: PII computer; 4 channels; wide-band (50khz – 2 Mhz) sensors**

C/SiC Composites Studied

Supplier	C Fiber	Matrix	Interface (Fiber Coating)
Honeywell ACI	T300 (1K)	CVI SiC	PyC Coating
Honeywell ACI	T300 (1K)	CVI/MI* SiC	PyC Coating
Hyper-Therm, Inc.	T300 (3K)	CVI SiC	Multilayer Coating (SiC and C)
Hyper-Therm, Inc.	T300 (3K)	CVI SiC	Pseudo-Porous Coating (SiC and C)
Hyper-Therm, Inc.	IM7 (6K)	CVI SiC	Multilayer Coating (SiC and C)
Hyper-Therm, Inc.	IM7 (6K)	CVI SiC	Pseudo-Porous Coating (SiC and C)

- All 2D [0/90] layups.
- All tensile samples (6 x 0.5 in.) were CVI SiC seal coated.

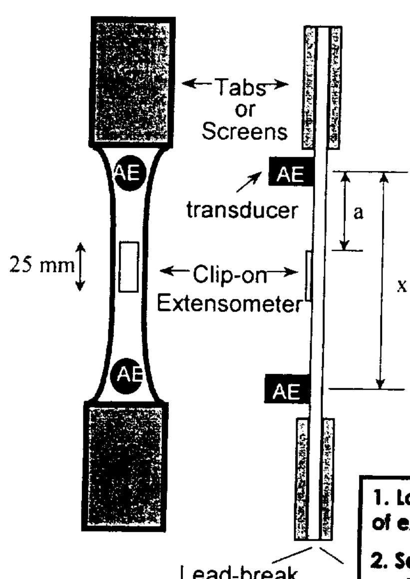
* Melt-infiltrated (MI), most pores filled with SiC slurry and molten Si infiltration

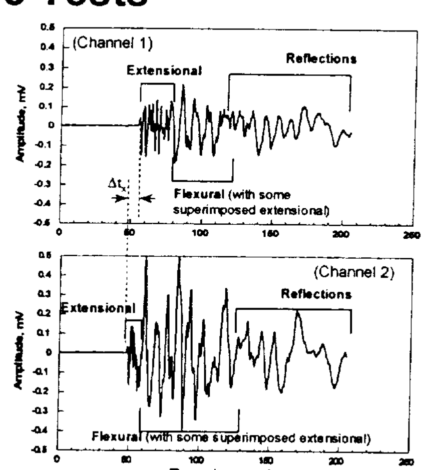
Modal AE involves the digitization of captured waveforms using wide-band frequency sensors as opposed to traditional AE which uses resonant frequency sensors.

Modal AE offers more quantitative analysis of AE, compared to traditional AE, for assessing damage accumulation because the entire frequency spectrum of the waveform is used:

- Accurate location of damage event
- Accurate measurement of speed of sound
  - can be used to measure Elastic Modulus
- AE parameters can be used to identify different events
  - Frequency content; separation of extensional wave and flexural wave, energy content...
  - Neural Network Classification of Waveforms

Modal Acoustic Emission Set-Up for Tensile Tests





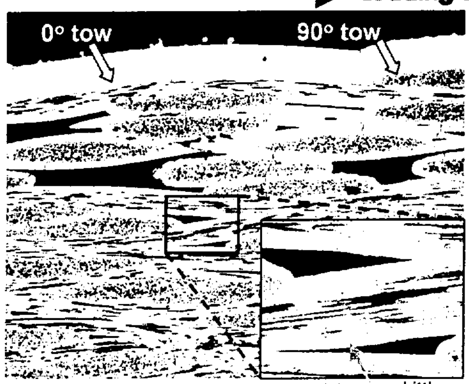
1. Locate events from difference in time of arrival (Δt) of extensional wave at each sensor, i.e., first peak.

2. Select only the events that occurred in the gage section for analysis.

Damage Accumulation in C/SiC Composites

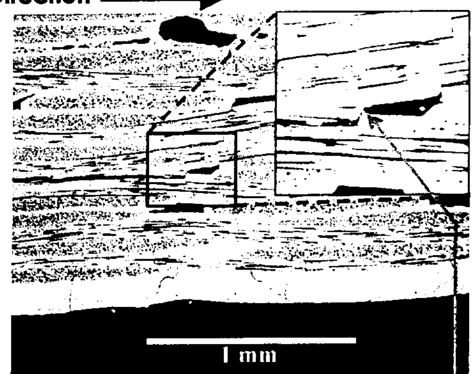
- after G. Camus, L. Guillaumat, and S. Baste, "Development of Damage in 2D Woven C/SiC Composite Under Mechanical Loading: I. Mechanical Characterization," *Comp. Sci. Tech.* Vol. 56, pp. 1363-1372 (1996)

Loading Direction



As-Produced T300 CVI SiC

Little cracking in 0° bundles not adjacent to 90° bundles (as-produced)

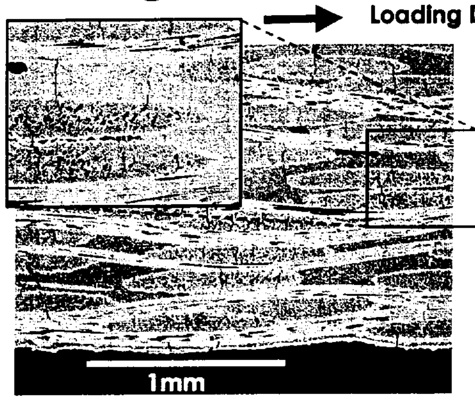


After Failure T300 CVI SiC

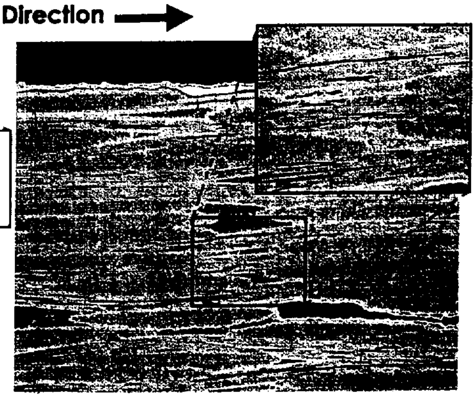
1. For as-produced material, tunnel cracks originate in 90° bundles and propagate transversely through 0° bundles during cool-down after composite fabrication
2. In tension, most additional matrix cracking occurs at 0° bundles that are not adjacent to 90° bundles. Little cracking occurs in 0° bundles adjacent to 90° bundles.

Damage Accumulation in C/SiC Composites

Loading Direction



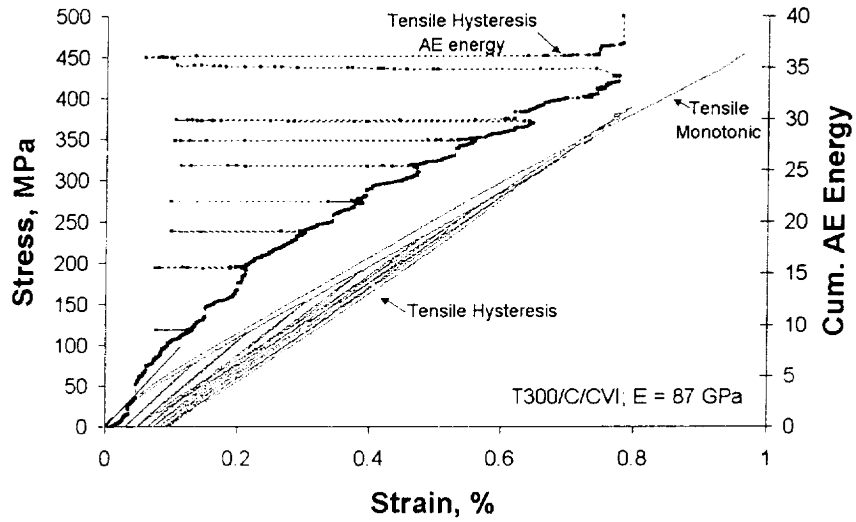
As-Produced T300 MI SiC



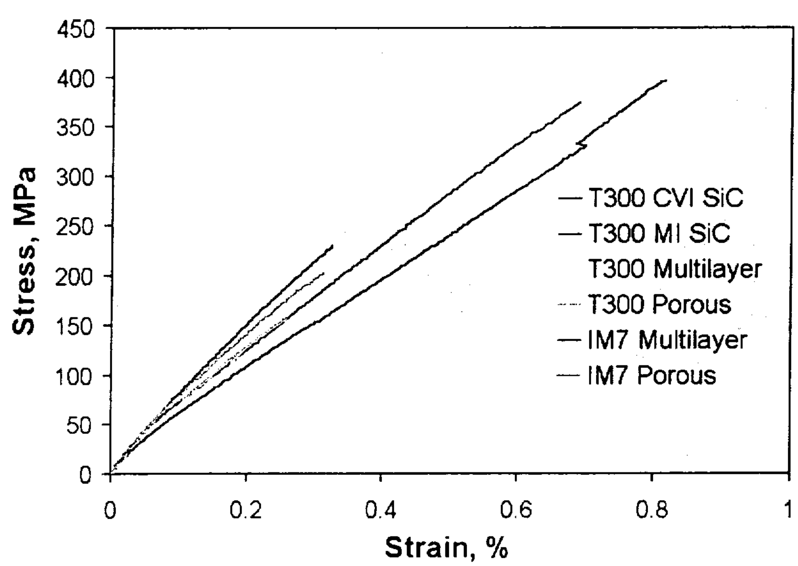
After Failure T300 MI SiC

More matrix cracks were observed in MI composites for both the as-produced and post-test specimens. This was unexpected since the thermal expansion difference between the C fibers and the Si containing matrix should be less and the residual tensile stress in the matrix reduced. One possible explanation is that the dense matrix of MI composites enables matrix cracks from 90° bundles to propagate through un-reinforced regions of the matrix creating a significant enough stress-concentration for cracks to propagate through 0° bundles not adjacent to 90° bundles.

Typical Tensile and AE Data



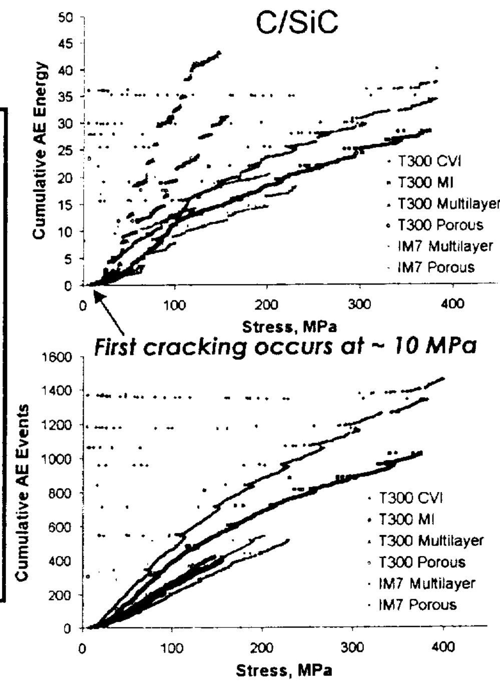
Stress-Strain Curves for Different C/SiC Composites (Hysteresis Loops Removed)



Comparing AE Data

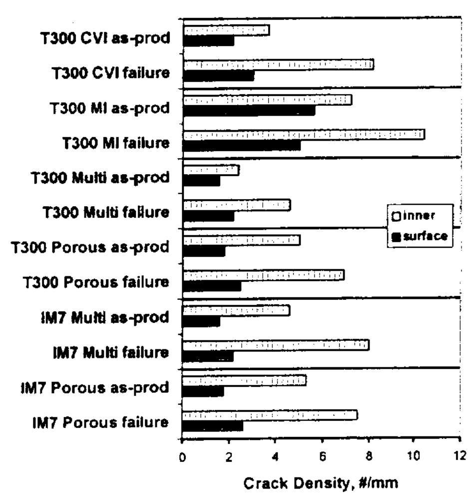
For studies using modal AE to monitor damage accumulation in SiC/SiC, it was found that the *relative amount* of cumulative AE ENERGY is directly related to the number of transverse matrix cracks. The *absolute magnitude* of AE energy depends on sensor contact and other factors.

Therefore, matrix crack formation/growth is greatest between ~ 10 and 150 MPa. Although, significant accumulation of AE energy occurs at higher stresses as well indicating continued matrix cracking. The same trends are observed for the number of events as well.



Transverse Matrix Crack Density

Surface = crack density through seal coat
Inner = crack density along the length of an interior 0° bundle

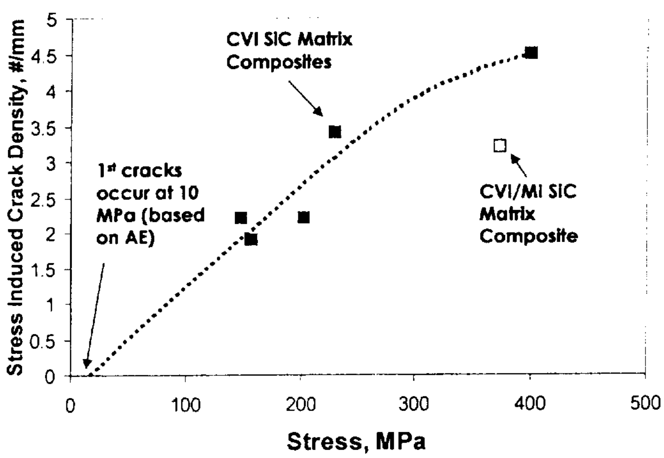


Matrix cracking through the seal coat changed little if at all after tensile loading.

Inner matrix cracking increased by approximately a factor of two with tensile loading.

Surprisingly, the as-produced and final MI matrix crack density was the highest as described above.

Stress-Dependent, Stress-Induced Matrix Crack Density



For CVI SiC matrix composites, the number of matrix cracks that occur during tensile testing appears dependent on the peak stress from the tensile test. Even though the composites had different starting crack densities and consist of different fibers, interphases, and CVI SiC (vendors).

Summary and Conclusions

- Matrix crack formation occurred as follows:
  - Most as-processed cracks occur from 90° bundles that propagate through the thickness, i.e., adjacent 0° bundles
  - Stress-induced cracks occur through 0° bundles not adjacent to 90° bundles
  - This was in accordance with Camus et al. (1996)
- AE indicates that 1st matrix cracking occurs at ~ 10 MPa and continues nearly up to failure, although the highest rate of matrix cracking occurs below 150 MPa
- MI composites had the highest as-processed and after-tensile-testing matrix crack densities, even though the lower thermal expansion coefficient of Si should have lessened as-produced matrix cracking. This was attributed to the increased density of MI SiC composites.