Lifetime prediction with acoustic emission during static fatigue tests on ceramic matrix composite at intermediate temperature under air

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Context - objectives

Ceramic Matrix Composites (CMCs) : Very attractive candidates for civil aircrafts applications due to their low weight/mechanical ratio and their high temperature strength. Developed for new generations of civil aircrafts engines**.** Very long lifetimes in service conditions (>20,000 hours) are unattainable during laboratory tests

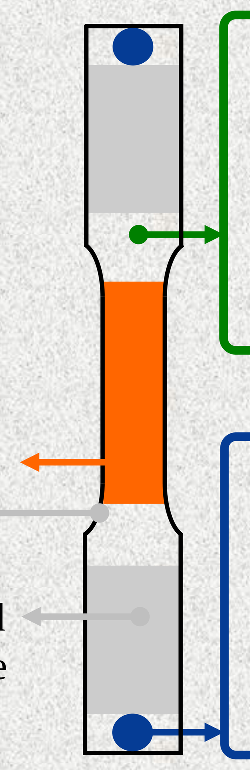
Objectives : Propose an AE based approach to real-time prediction of the remaining lifetime of CMCs during long term mechanical tests.

Acoustic Emission monitoring of CMCs at two scales

Static fatigue tests up to 500°C under air

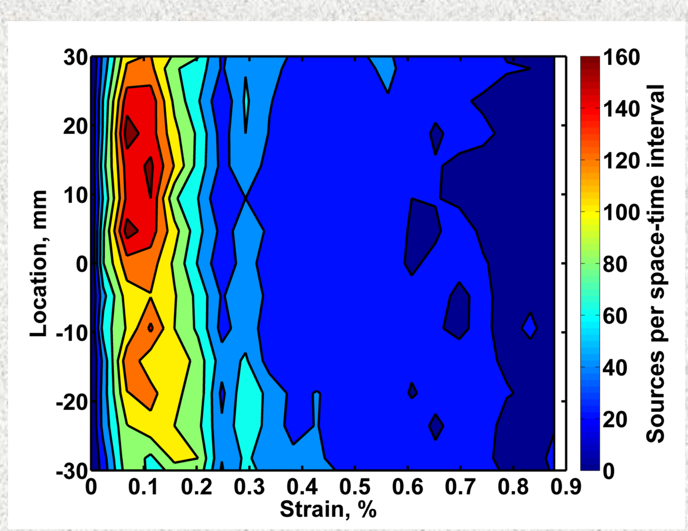
Temperature-controlled zone with direct elongation measurement

Load or displacement controlled loading on a pneumatic machine



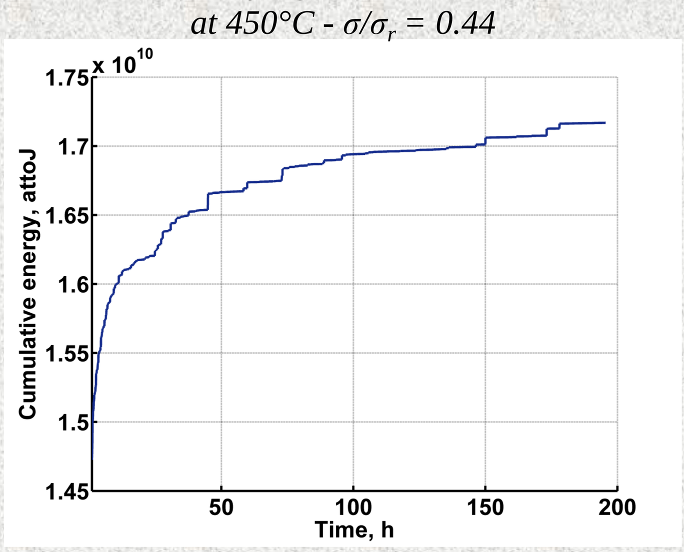
CMCs
SAFRAN Herakles
Nicalon fiber architecture
PyC interphase
Hybrid [Si-B-C] self-healing matrix

Acoustic Emission
2 µ80 sensors connected to a PCI-2 system (MISTRAS)
2 recorded signals per source with arrival time, stress and strain values



Monotonic tensile test on CMC at room temperature

Static fatigue test on CMC at 450°C - σ/σ_r = 0.44

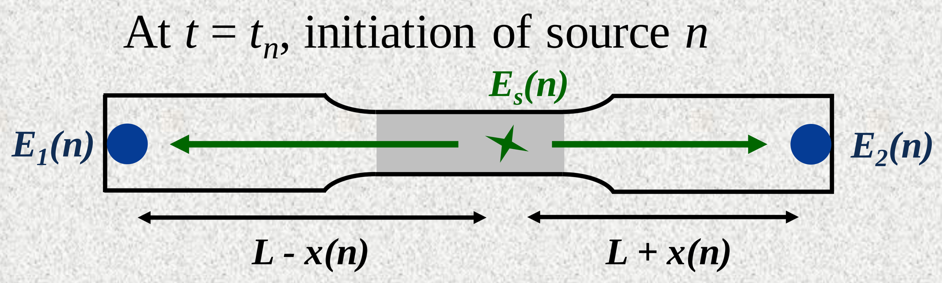


Real-time data on initiation and damage kinetics evolution

Energy and attenuation

It is generally accepted that the energy of an AE signal is related to the energy released by the source at crack initiation. Various parameters affect the recorded energy: distance of wave propagation, energy attenuation due to damage

At $t = t_n$, initiation of source n



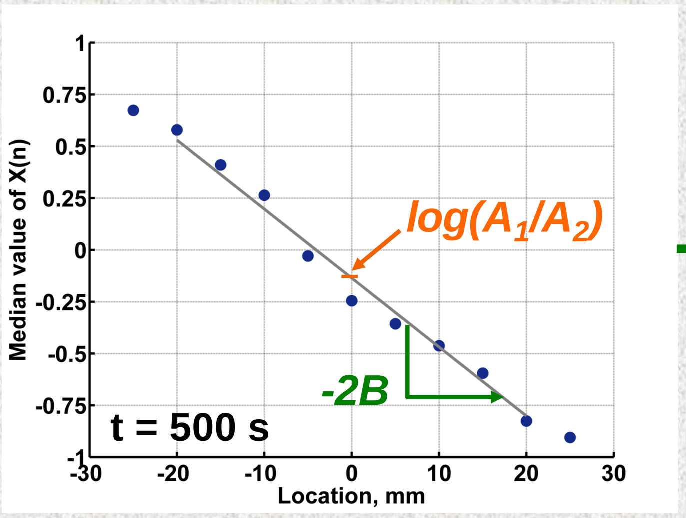
Recorded energies E_1 and E_2

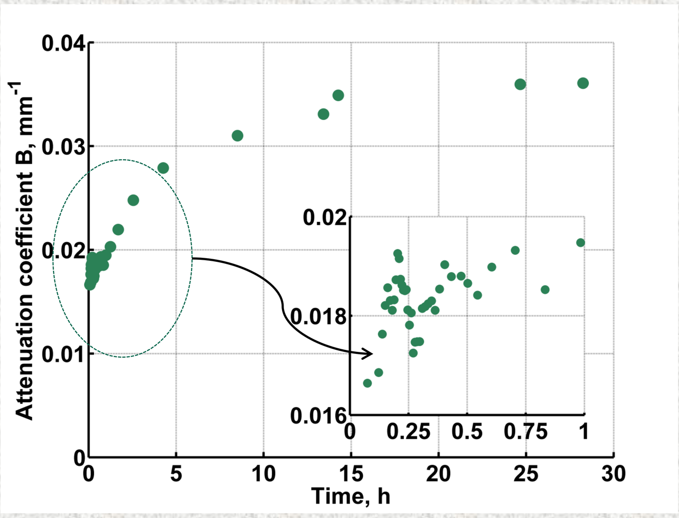
$$\begin{cases} E_1(n) = E_s(n).A_1.e^{-B.[L-x(n)]} \\ E_2(n) = E_s(n).A_2.e^{-B.[L+x(n)]} \end{cases}$$

$$X(n) = \log\frac{E_1(n)}{E_2(n)} = \log\frac{A_1}{A_2} - 2B.x(n)$$

$A_{1,2}$: sensor coupling

B : attenuation coefficient





Static fatigue test on CMC at 500°C - σ/σ_r = 0.95

For ceramic matrix composites under static fatigue loading, a significant increase of energy attenuation is observed during the first half of tests. This increase of attenuation is associated to transverse matrix crack opening.

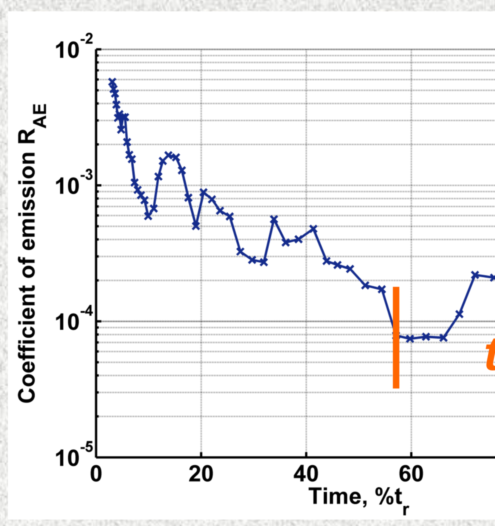
Characterization of energy release acceleration

Detection of acceleration

Coefficient of emission R_{AE}

$$R_{AE}(i) = \frac{1}{E_{loading}}\frac{\Delta E(i)}{\Delta t(i)}$$

The increment of energy released during a time interval divided by the energy released during initial loading.



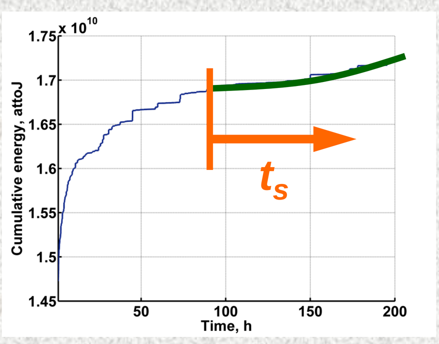
Critical aspect prior to rupture

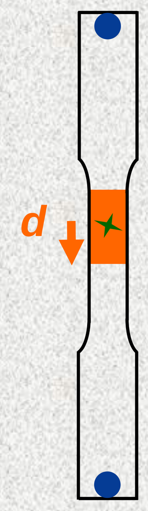
Modeling with Benioff law [Bufe 1993]

$$\Omega(t) = \sum_{n=1}^{N(t)} \sqrt{E_s(n)} = A + B.(t_r - t)^m$$

The model based on Benioff's law provides a satisfactory approximation of the AE release-process acceleration after the minimum of the coefficient R_{AE}.
This result suggests that as the damage increases, especially after the minimum of
Coefficient R_{AE}, a new stage appears leading to ultimate fracture.
This avalanche phenomenon may be linked to the delayed failure of fibres
(slow crack growth, oxidation).

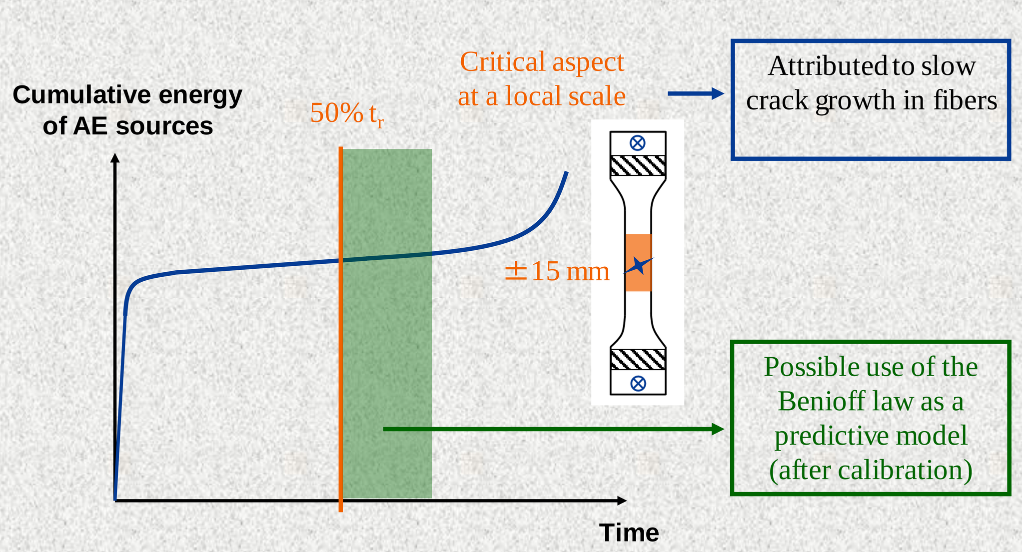
Optimum Circle Method [Bowman 1998]
- After what time t_s*?
- What region around the rupture point ±d*?





Results: ***Static fatigue tests on CMCs at 450°C and 500°C***

- Real-time detection of acceleration at 55% of rupture time
- AE detected signals correspond to a critical energy release at local scale (±15 mm)
- Damage mechanism attributed to slow crack growth in fibers



A criterion denoted R_{AE} was defined, which allows prediction of the time-to-rupture using AE activity recorded during the first half of the test. This criterion is a reliable indicator of the beginning of a new damage stage leading to ultimate fracture.

Therefore, the monitoring of the attenuation coefficient B constitutes a new indicator for damage monitoring of ceramic matrix composites. The characteristic evolution of attenuation coefficient B also allows considering the detection of the plateau as an indicator for lifetime prediction.

References:
Maillet et al. *Comp Sci Tech* 72:1001-1007 (2012)
Maillet E. et al. *Mechanical Properties and Performance of Engineering Ceramics and Composites* 33(2) 15-25 (2012)
Momon et al. *Comp: Part A* 43:254-260 (2012)
Momon et al. *Comp: Part A* 41:913-918 (2010)
Moevus et al. *Comp Sci Tech* 68:1250-1257 & 1258-1265 (2008)