Euratom cea

DRN

The Mechanical Behavior of SiC_f/SiC Composites

Fibers↔matrix interactions:

non-linear elastic behavior due to damage mechanisms

(matrix micro-cracking and matrix-fibers decohesion)

Two main damage (micro-fissuring) modes exist in CMCs:

- microcracks whose directions are related to the fibers' directions (the axes of initial anisotropy of the material)
- microcracks whose directions are related to the loading directions

Euratom cea

DRN

Damage Models for Ceramic Matrix Composites

Framework: Continuous Damage Mechanics

✓ Model based on scalar internal variables *(ONERA)*

pros: - *easy implementation in FEM codes*
- *3D formulation*

cons: - *it is impossible to describe damage effects related to loading directions*
- *difficult to identify*

✓ Model based on vectorial internal variables (*LMT Cachan*)

pros: - *it takes into accounts both types of damage*
- *easy to identify*

cons: - *it is difficult to separate the effects of the two types of damage*
- *(initial) 2D formulation*

✓ Model based on vectorial and scalar internal variables (*ONERA*)

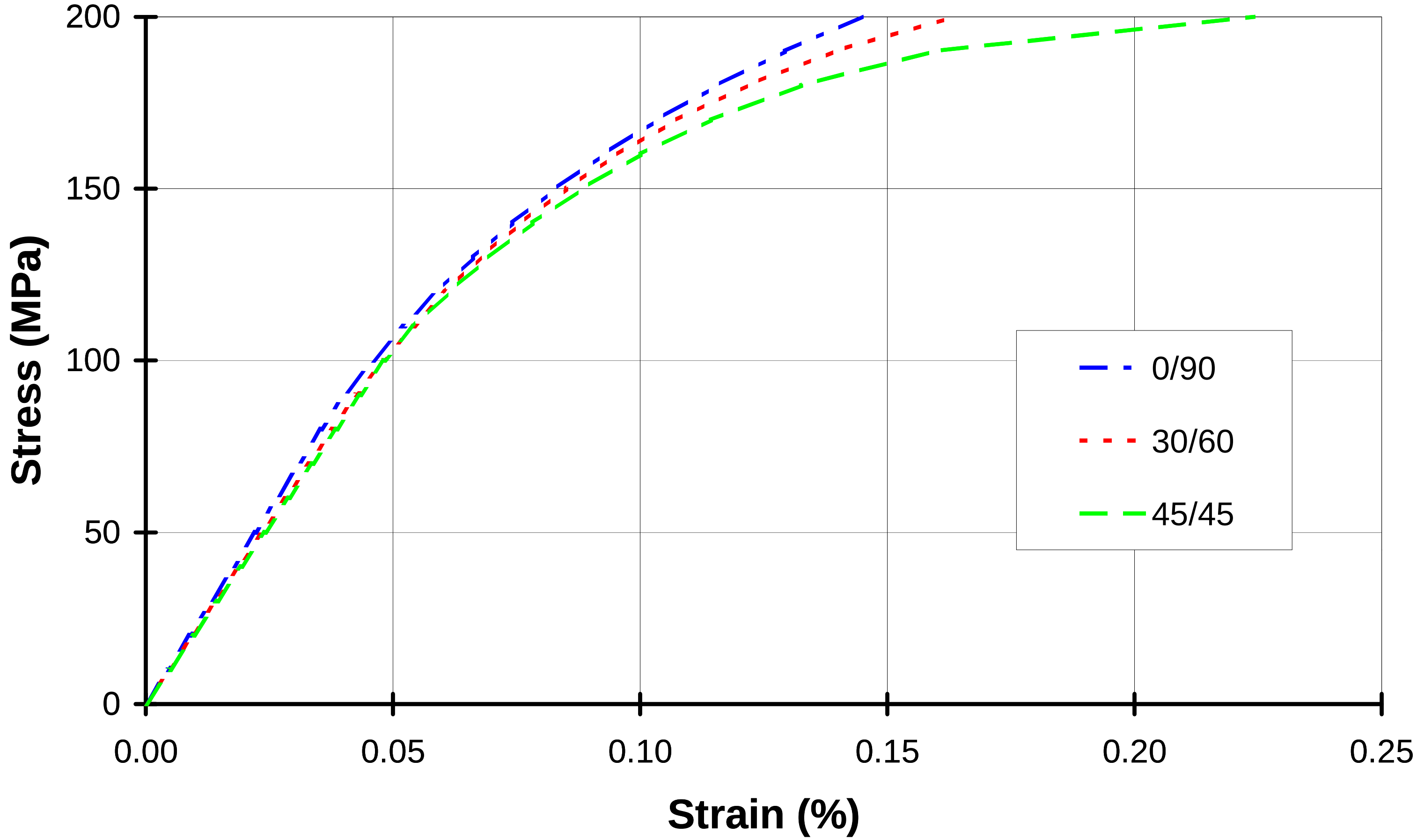
pros: - *accurate description of both damage modes*
- *3D formulation*

cons: - *implementation in FEM codes may be complicated by numerical instabilities*
- *difficult to identify*

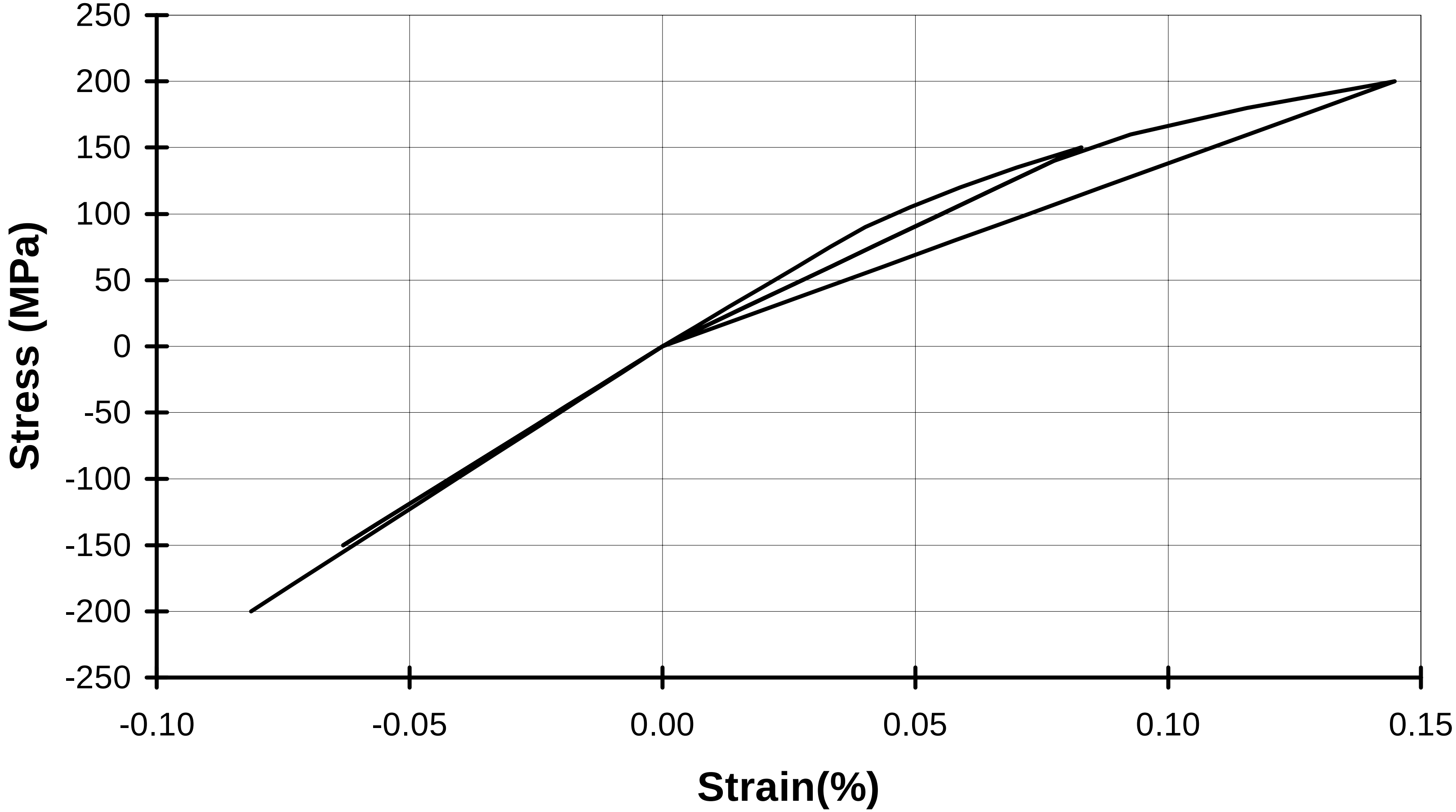
Euratom cea

DRN

Simulation of Tension Tests for Different Fibers Inclinations



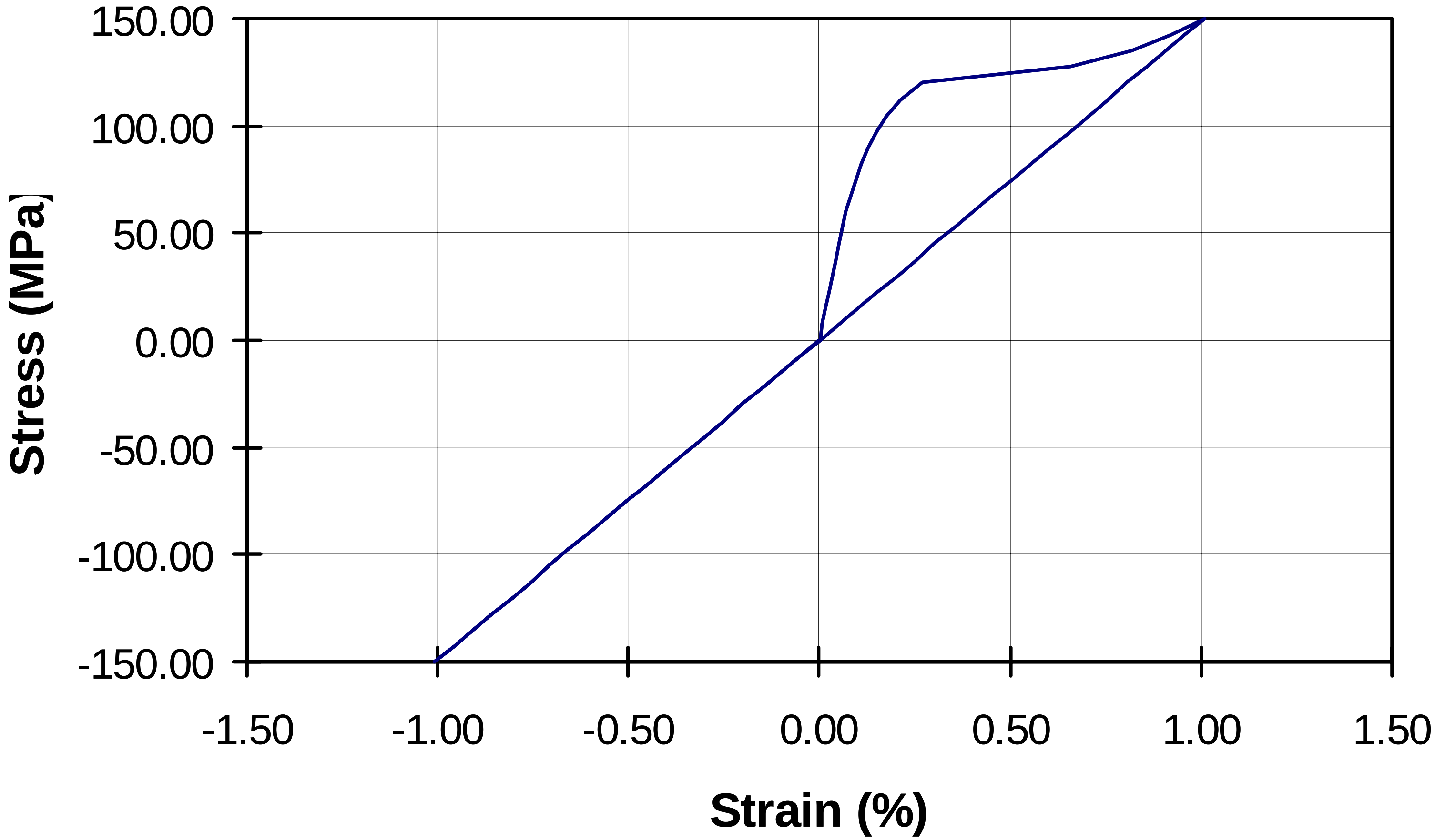
Simulation of Incremental Tension-Compression Test at 0°



Euratom cea

DRN

Simulation of Shear Test at 0°



Euratom cea

DRN

Mechanical Tests Needed to Identify the Model(s)

- Tension test on 0/90 specimen (with measurement of ε_1 and ε_2).
- Tension test on a +/- 45 specimen (with measurement of ε_1 and ε_2).
- Incremental tension-compression test on 0/90 specimen (with measurement of ε_1 and ε_2).
- Compression test on a 0/90 specimen (with measurement of ε_1 and ε_2).
- *Tension test through the thickness.*
- *Compression test through the thickness*

Further mechanical tests are anyway necessary to validate the model

Resistance Criteria

CMCs present different strengths depending on the loading direction. Also tensile and compression strengths strongly differ.

☞ Stresses in plane have been evaluated using the Von Mises criterion.

↳ Limits: 145 MPa for tensile stresses (correspondingly roughly to the beginning of microcracks opening, elastic limit is 110 MPa)
580 MPa for compressive stresses (rupture limit - CERASEP N2-1).

☞ Stresses through the thickness have been separately investigated:

↳ Normal stress limits: 110 MPa for tensile stresses (no data available).
420 MPa for compressive stresses
(rupture limit - CERASEP N2-1)

↳ Shear stress limit: 44 MPa (SEP data)

Resistance Criterion for Plane Stresses

$$\left(\frac{\langle\sigma_1\rangle^+}{\langle\sigma_0\rangle^+}\right)^2+\left(\frac{\langle\sigma_1\rangle^-}{\langle\sigma_0\rangle^-}\right)^2+\left(\frac{\langle\sigma_2\rangle^+}{\langle\sigma_0\rangle^+}\right)^2+\left(\frac{\langle\sigma_2\rangle^-}{\langle\sigma_0\rangle^-}\right)^2-\left(\frac{\langle\sigma_1\rangle^-\langle\sigma_2\rangle^-}{\langle\sigma_0\rangle^-\langle\sigma_0\rangle^-}\right)-\left(\frac{\langle\sigma_1\rangle^+\langle\sigma_2\rangle^+}{\langle\sigma_0\rangle^+\langle\sigma_0\rangle^+}\right)-\left(\frac{\langle\sigma_1\rangle^-\langle\sigma_2\rangle^+}{\langle\sigma_0\rangle^-\langle\sigma_0\rangle^+}\right)-\left(\frac{\langle\sigma_1\rangle^+\langle\sigma_2\rangle^-}{\langle\sigma_0\rangle^+\langle\sigma_0\rangle^-}\right)=1$$

where:

σ_1, σ_2 are the principal stresses

$\langle\ \rangle^-$ and $\langle\ \rangle^+$ represent respectively the positive and the negative values of the quantity

$\langle\sigma_0\rangle^-$ and $\langle\sigma_0\rangle^+$ represent respectively the assumed resistance limit under compression and under tension.

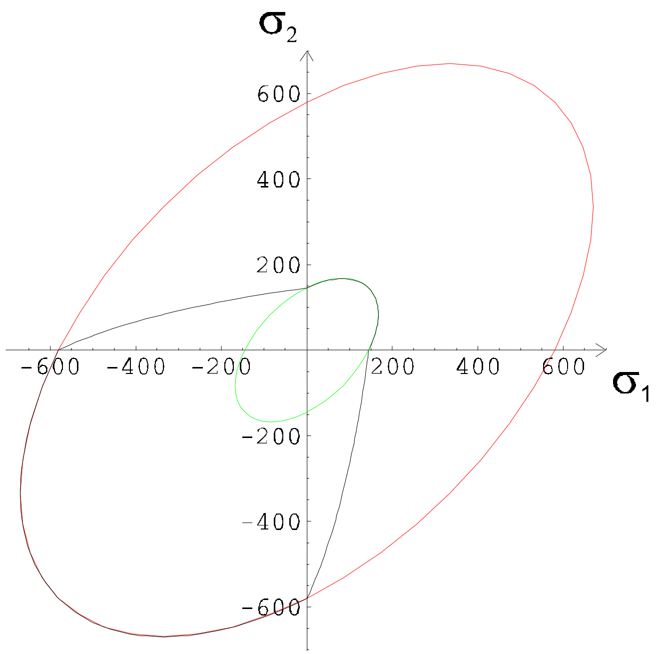
This criterion is isotropic, but capable to account for the different resistance limits under tension and compression

Resistance Criterion for Plane Stresses

Von Mises criterion, σ_{lim}=145 Mpa

Von Mises criterion, σ_{lim}=580 MPa

Criterion adopted for plane stresses, σ^{+}=145MPa, σ^{-}=580 Mpa



Tests needed to determine the resistance limits:

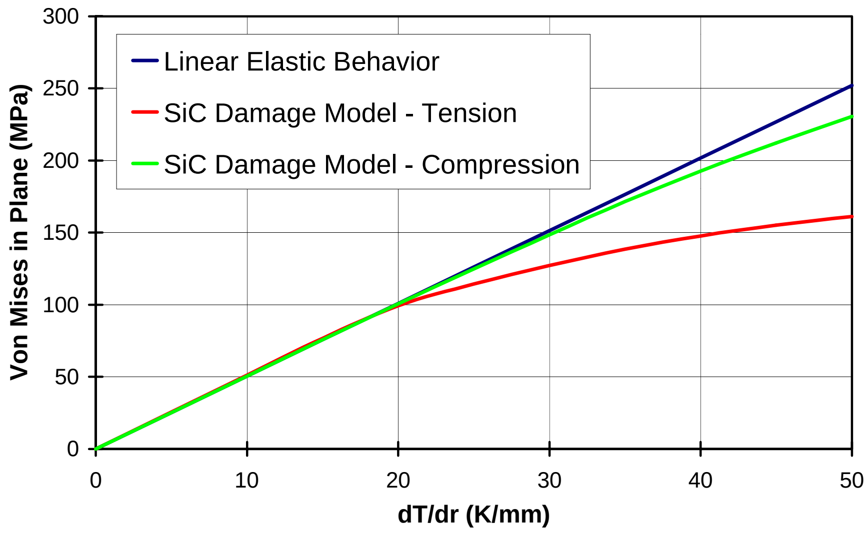
tension and compression tests at 0° (up to rupture)

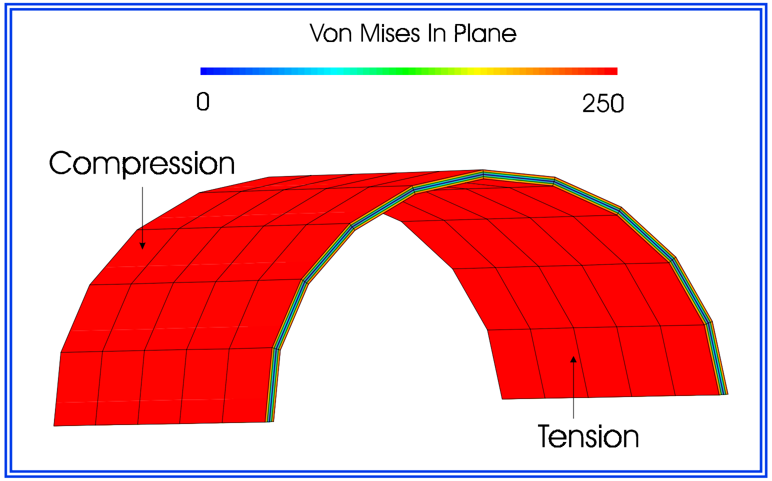
The same tests are needed to determine the resistance limits through the thickness

Thermal Load

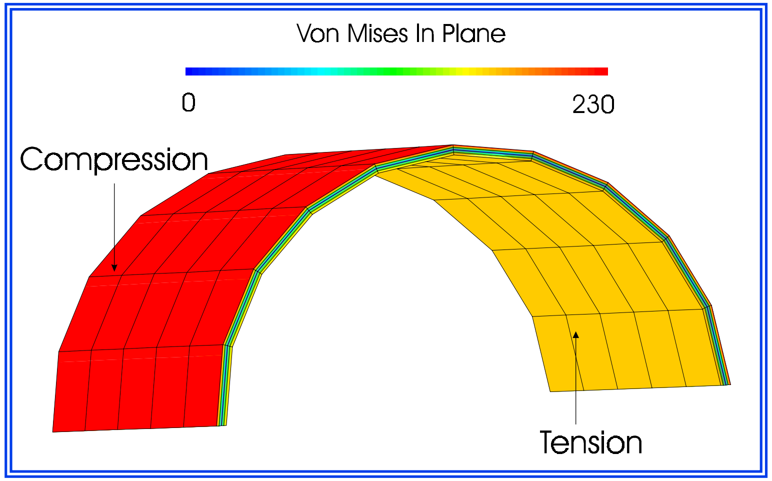
<u>Case studied:</u> 10mm-thick tube with a constant temperature gradient through the thickness

- Stress distribution is not symmetric.
- Differences increase with the thermal gradient.





Linear Elastic Behavior



SiC/SiC Damage Model

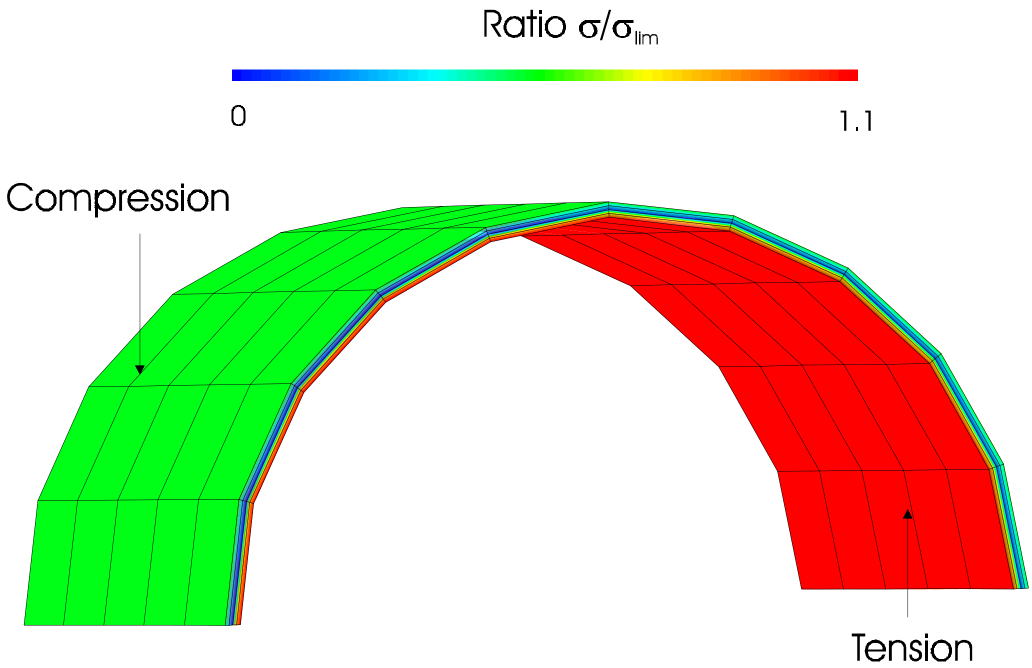
Conclusions

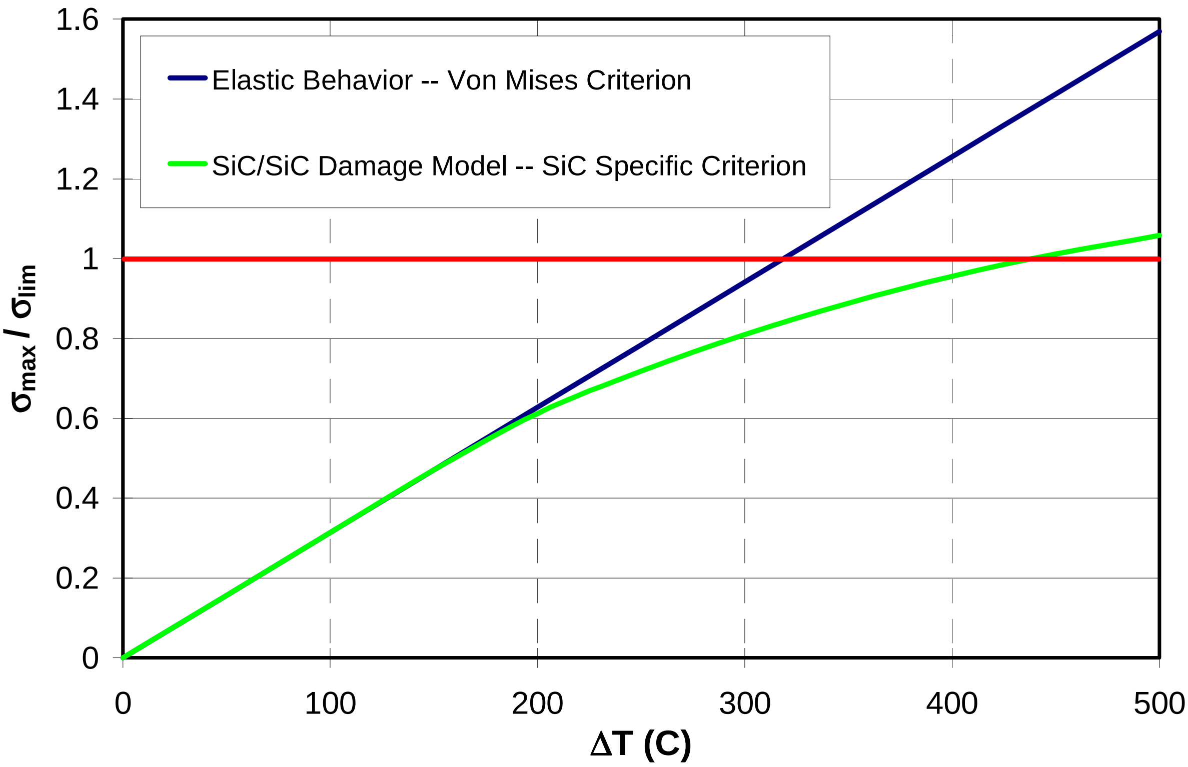
- SiC_f/SiC composites have a strong non-linear mechanical behavior that has to be taken into account in thermo-mechanical analyses.
  - Specific damage models have been identified and implemented in FEM codes (CASTEM 2000)

- Appropriate design criteria are also needed to correctly asses the material's resistance limits.
  - A new criterion has been introduced and used in the latest analyses

Mechanical tests needed to identify both the model and the criterion are classical tension/compression tests

Thermal Load: Influence of the New Criterion





G. Aiello, CEA - Saclay