SiC\textsubscript{f}/SiC CERAMIC MATRIX COMPOSITES (CMC) APPLIED TO NUCLEAR FUSION

DEVELOPMENT STATUS AND MANUFACTURING CAPABILITIES
SNECMA's SiCf/SiC COMPOSITES DEVELOPMENTS APPLIED TO NUCLEAR FUSION: history and Snecma's contribution

As a world leader in the field of CMC materials, SNECMA has been provided his expertise since 1990 for the development of specific SiCf/SiC composites grades materials tailored to the requirements of nuclear fusion.

These activities, developed within the European Breeding Blanket Concept for the Fusion Power Reactor Program of the EEC, have led to the development and manufacturing of new SiCf/SiC materials combining a number of attractive properties:

- low activation;
- good resistance to shocks and heat cycling;
- high mechanical properties to temperatures of over 1000°C;
- possibility to manufacture some complex shapes.

SNECMA additionally offers:

- the largest industrial facilities worldwide for the manufacturing of SiCf/SiC composites parts;
- a complete assistance in design, modelisation, calculation and high temperature characterisation activities.
SNECMA's SiC\textsubscript{f}/SiC COMPOSITES DEVELOPMENTS APPLIED TO NUCLEAR FUSION: OVERVIEW AND PRODUCTS PORTFOLIO.

CERASEP N2-1  \[\rightarrow\]  Nicalon fibre
              2D texture
              SiC ICVI matrix

CERASEP N3-1  \[\rightarrow\]  Nicalon fibre
              Guipex\textsuperscript{\textregistered} 3D texture
              SiC ICVI matrix

CERASEP N4-1  \[\rightarrow\]  Hi-Nicalon fibre
              Guipex\textsuperscript{\textregistered} 3D
              SGC ICVI matrix

Further developments with high purity fibres upon request

- Increased working temperature
- Improved thermal conductivity
- Improved interlaminar shear strength
- Better behaviour under irradiation
SNECMA's SiC_{f}/SiC COMPOSITES DEVELOPMENTS APPLIED TO NUCLEAR FUSION : MANUFACTURING CAPABILITIES.

GEOMETRICAL POSSIBILITIES:

Guipex® 3D

- Plates
- Opened shell
- 3D complex parts

With curve radius > 1.5 X texture thickness

LINKS:

Common

- Rivet
- Screw

Advanced

- Brasing technique
- Stitching
- Sticking of preforms and co-infiltration
SNECMA's SiC\textsubscript{f}/SiC COMPOSITES . MANUFACTURING MEANS.

- Full texture manufacturing shops capable of 2D, 3D and 4D textures fabrication. Flat panels (width from 500 to 2600mm, length from 500 to 6000mm), cylindrical and conical means (up to 2600mm diameter).

- Largest densification furnaces worldwide (up to 2,5 meters diameter). Isothermal Chemical Vapor Infiltration process (SiC and PyC matrix). Resin and pitch impregnation units, carbonization furnaces.

- Full integrated design, modelisation, process R&D and composite material expertise enabling the combination of the above industrial means according to applications requirements.

- World leading expertise and facilities in thermo-mecanical characterization.
SNECMA's $\text{SiC}_f/\text{SiC}$ COMPOSITES DEVELOPMENTS APPLIED TO NUCLEAR FUSION: NEXT FORESEEN DEVELOPMENTS.

**Objectives:**
- improve thermal conductivity;
- improve the irradiation behavior.

**Irradiation behavior:**
improve the purity of the material.

Use of new stoechiometric fibers

**Thermal conductivity:**
decrease the porosity of the material.

New matrix grade embedding siliconization: RSG (Reactive Siliconized Grade), $\text{SiC}_f/\text{SiC} + \text{Si}$, combining the superior mechanical characteristics provided by the CVI matrix with the good thermal conductivity properties generated by the siliconization.
SNECMA's SiC\textsubscript{p}/SiC COMPOSITES APPLIED TO NUCLEAR FUSION: MATERIAL MEASURED PROPERTIES.

<table>
<thead>
<tr>
<th>Property</th>
<th>Temperature</th>
<th>CERASEP® N2-1</th>
<th>CERASEP® N3-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>RT</td>
<td>&gt; 2.4 g/cm\textsuperscript{3}</td>
<td>&gt; 2.4 g/cm\textsuperscript{3}</td>
</tr>
<tr>
<td>Porosity</td>
<td>RT</td>
<td>10 %</td>
<td>10 %</td>
</tr>
<tr>
<td>Fibre content</td>
<td>RT</td>
<td>40 %</td>
<td>40 %</td>
</tr>
<tr>
<td>Tensile stress (in plane)</td>
<td>RT</td>
<td>285 Mpa</td>
<td>300 Mpa</td>
</tr>
<tr>
<td>Tensile strain (in plane)</td>
<td>RT</td>
<td>0.75 %</td>
<td>0.80 %</td>
</tr>
<tr>
<td>Tensile modulus (in plane)</td>
<td>RT</td>
<td>200 Mpa</td>
<td>200 Mpa</td>
</tr>
<tr>
<td>Translaminar shear stress</td>
<td>RT</td>
<td>200 Mpa</td>
<td>200 Mpa</td>
</tr>
<tr>
<td>Thermal conductivity (through thickness)</td>
<td>RT 800°C</td>
<td>9 W/m.K</td>
<td>13 W/m.K</td>
</tr>
<tr>
<td></td>
<td>1000°C</td>
<td>5.8 W/m.K</td>
<td>7.6 W/m.K</td>
</tr>
<tr>
<td></td>
<td>1000°C</td>
<td>5.7 W/m.K</td>
<td>7.5 W/m.K</td>
</tr>
<tr>
<td>CTE (in plane)</td>
<td>1000°C</td>
<td>4.10\textsuperscript{-6}/K</td>
<td>4.10\textsuperscript{-6}/K</td>
</tr>
</tbody>
</table>

Note: CERASEP® N4-1, including Hi-Nicalon fibres, is not characterized yet. Samples produced in 1999.