Feasibility Study for C/C-SiC Sandwich Structures

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Wissen für Morgen
Outline

- C/C-SiC materials
- Motivation
- Manufacture of C/C-SiC sandwich structures via LSI
- Test results
- Summary and outlook
C/C-SiC Manufacture via Liquid Silicon Infiltration (LSI)

Precursor     Additives      Fibers
Silicon Granules

CFRP (Shaping)
T < 250 °C

Pyrolysis
T > 900 °C

Siliconization
Si + C → SiC
T > 1500 °C

CFRP
C/C
C/C-SiC
General Properties of C/C-SiC Materials

Thermal shock resistance

Wear resistance
Low density

Adjustable microstructure / properties

Damage tolerance

Internal oxidation protection

Low CTE
II : - 0.5 to 2.5 ppm
\( \perp \) : 2 – 7 ppm
Sandwich Design

Sandwich Panel

Face skins
High tensile / compression strength and moduli

Core
• Sufficient shear strength
• Lightweight

I-Beam

Web
Flanges

Hexcel Composites, 2000;
Why Sandwich?

<table>
<thead>
<tr>
<th></th>
<th>Solid Material</th>
<th>Core Thickness t</th>
<th>Core Thickness 3t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stiffness</td>
<td>1</td>
<td>7</td>
<td>37</td>
</tr>
<tr>
<td>Flexural Strength</td>
<td>1</td>
<td>3.5</td>
<td>9.2</td>
</tr>
<tr>
<td>Weight</td>
<td>1</td>
<td>1.03</td>
<td>1.06</td>
</tr>
</tbody>
</table>

Hexcel Composites, 2000; Y.Klett 2013
Target Applications of C/C-SiC Sandwich Structures

- Thermally stable telescope structures (CTE ≈ 0 ppm)
- Highly stiff and lightweight panels for satellite structures
- Charging carriers for high temperature furnaces

Others:
- Cooled structures for propulsion or TPS
- High temperature heat exchangers
- ...

Schunk Kohlenstofftechnik


Schunk Kohlenstofftechnik
Manufacture of C/C-SiC Sandwich Structures

Skins → Core → Joining (Polymer + C) → Sandwich structure (360 x 330 x 15 mm³)

Processes:
- Warm pressing: CFRP Preforms
- Pyrolysis: C/C Preforms
- Siliconization: C/C-SiC Structure
Manufacture of C/C-SiC Sandwich Structures

3 methods for manufacturing skin preforms

Skins → Core

Joining
Polymer + C

Sandwich structure
(360 x 330 x 15 mm³)

Warm pressing
CFRP Preforms

Pyrolysis
C/C Preforms

Siliconization
C/C-SiC Structure
## Preform Manufacture

<table>
<thead>
<tr>
<th></th>
<th>Core</th>
<th>Skin Panel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Material</td>
<td>PH 2291</td>
<td>HP 814</td>
</tr>
<tr>
<td>Prepreg</td>
<td>PP 111</td>
<td></td>
</tr>
<tr>
<td>Lay up</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CFPR / C/C</td>
<td>1 layer 0°/90° ±45°</td>
<td>3 layers 0°/90°</td>
</tr>
<tr>
<td>preform manufacture</td>
<td>Folding + Warm pressing</td>
<td>Warm pressing</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$p_{\text{max}}$ [kPa]</td>
<td>5.8</td>
<td>3.9</td>
</tr>
<tr>
<td>$T_{\text{max}}$ [°C]</td>
<td>220</td>
<td>220</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Direct pyrolysis of prepreg</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt; 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>900</td>
</tr>
</tbody>
</table>
Properties of Skin Material Variants

- Fibre volume content of C/C preform increases with laminate pressure.
- No significant difference in density.
- Slightly higher open porosity of C/C-SiC based on low pressure CFRP preform.
Tension Properties of Skin Material (DIN 658-1)

- Highest performance of materials based on highly pressurized CFRP with high fibre content
- PH material selected for sandwich skins due to homogeneous siliconization
Manufacture of Cores via Folding Technology

- Prepreg with release tapes
- Folding and forming in wooden mould (380 x 400 mm²)
- Curing/ Postcuring at T = 130 / 210 °C
- CFRP fold core (360 x 330 x 13 mm³)
Folded Core - Geometry

W-Direction

L-Direction

90°

54.5°

13.4

13
Joining

- Joining paste: Phenolic resin (JK 60) + C particles (PC 40; < 45 µm)
- C/C-core preform dipped in joining paste with constant film thickness (3 mm)
- Curing of joining paste (220 °C / 4h)
- Joining of second skin
- C/C sandwich preform (360 x 330 x 15 mm³)
Results – Core Structure and Joining

- Single layer core material shows characteristic microstructure
- C/C-SiC core weight $\approx 100 \text{ kg/m}^3$
- C-rich joining after siliconization
  (71% C; 18% SiC; 11% Si)
- Homogeneously joined contact lines
## Sandwich Geometry

Fibre orientation in core

<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total thickness</td>
<td>h</td>
<td>15</td>
</tr>
<tr>
<td>Skin thickness (0°/90°)</td>
<td>t</td>
<td>1</td>
</tr>
<tr>
<td>Core height</td>
<td>c</td>
<td>13</td>
</tr>
<tr>
<td>Core wall thickness (0°/90° and ± 45°)</td>
<td>t_c</td>
<td>0.3</td>
</tr>
</tbody>
</table>

N. Gottschalk 2015
Coupon Geometry and Test Set Up

4 Pt. Bending according to DIN 53239

- \( b = 50 \)
- \( l = 260 \)
- \( L_{\text{direction}} \)
- \( W_{\text{direction}} \)
- \( L_S = 75 \)
- \( L_A = 230 \)
Results - Bending of Sandwich Structures

- Failure by tension fracture of lower skin
  (2 coupons out of 20 show shear failure of core)
- Load factor for the skins > 70 %
- Highest Stiffness in W-direction (joining lines II to sample length)
Sandwich Effectivity

High load factor for the skins (>70% of tensile strength from tension test)

Effective / measured stiffness > theoretical stiffness (+ 63 %)

Core is increasing stiffness of sandwich structure

Lighter core possible?
Comparison Sandwich Structure – Solid Plate

Bending test of solid plate with similar area weight (5.7/5.48 kg/m²) and fibre architecture (0°/90°). Sandwich showed:

- 80 times higher effective stiffness; 4-5 times higher load at fracture
- 50 % lower fracture strength
Summary

- Sandwich structures entirely made of C/C-SiC realized via LSI.
- Lightweight cores based on single layer C/C-SiC and LSI are possible (similar microstructure compared to multilayer C/C-SiC).
- Sandwich design offers highly stiff and lightweight C/C-SiC structures.
Outlook

- Use of high performance skin materials.
- Lighter core materials by using lighter fabrics (245 → 80 → 55 g/m²).
- Comparison with homogeneous core structures perpendicular to skins.
- Upscaling to praxis relevant sandwich structure (500 x 500 mm²; h ≥ 40 mm). Test of demonstrator.

Source: Hexcel
Thank you for your attention!
Manufacture of Cores via Folding Technology