C/C-SiC Sandwich Structures for Lightweight TPS and Hot Structures

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8th European Workshop on Thermal Protection Systems and Hot Structures

April 19 – 22. 2016
Noordwijk
Outline

- Motivation
- Manufacture of C/C-SiC sandwich structures via LSI
- Test results
- Summary and outlook
Why Sandwich?

<table>
<thead>
<tr>
<th></th>
<th>Solid</th>
<th>Sandwich</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bending stiffness/b¹</td>
<td>$E \cdot J$</td>
<td>$E_{\text{Skin}} \cdot J$</td>
</tr>
<tr>
<td>Panel thickness [mm]</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Panel weight¹ [kg/m²]</td>
<td>11.4</td>
<td>4.4</td>
</tr>
<tr>
<td>Prepreg layers</td>
<td>24</td>
<td>8</td>
</tr>
</tbody>
</table>

1 panel width = 1 mm

6 mm

17% higher thickness
62 % less weight
CMC Sandwich Application: Thermally Stable Structures

- Optical benches
- Telescope structures

Others:
- Charging carriers for high temperature furnaces
- High temperature heat exchangers
- ...

Current DLR concept proposes functional separation of insulation and load bearing CMC shell
Self-standing CMC panels resting on dedicated CMC load introduction elements
Design for stiffness according to pressure requirements
SHEFEX design e.g. proposes un-stiffened plates with uniform thickness as panels
Easy to manufacture but not effective → Increases mass and limits panel size
Sandwich can be designed exactly to pressure requirement to optimise area mass and size of acreage TPS
CMC Sandwich Application: Hot Control Surfaces

- Hot control surfaces essential for hypersonic cruise and entry vehicles
- High pressure loads, temperature gradients
- Stiffness required for shape stability
- Hot structures preferred (low temperature gradients and distortions, limited space)
- Low inertia required for fast-moving control systems
- Sandwich design can be tailored to structural / thermal requirements
C/C-SiC / SiC Honeycomb

- Cracks and delaminations (CTE-mismatch)
- high core masses
- Brittle fracture behaviour of core

M. Kütemeyer (DLR), M. Kuhn (DLR), A. Ortona (SUPSI), Gianella (EngiCer), 2015
Warm pressing
210 °C
CFRP Preforms

Pyrolysis
1650 °C / N₂
C/C Preforms

Siliconization
Si + C → SiC
1650 °C / vacuum
C/C-SiC Structure

Manufacture of All C/C-SiC Sandwich Structures

Skins

Core

Joining
(Polymer + C), 220 °C
C/C structure
# CFRP Preform Manufacture

<table>
<thead>
<tr>
<th></th>
<th>Core</th>
<th>Skin Panel</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Raw Material</strong></td>
<td>Prepreg: C fibre fabric (245 g/m²) + Phenol-Resol</td>
<td></td>
</tr>
<tr>
<td><strong>Lay up</strong></td>
<td>1 layer 0°/90° and ±45°</td>
<td>3 layers 0°/90°</td>
</tr>
<tr>
<td><strong>CFRP preform manufacture</strong></td>
<td>Folding + Warm pressing</td>
<td>Warm pressing</td>
</tr>
<tr>
<td><strong>p&lt;sub&gt;max&lt;/sub&gt; [kPa]</strong></td>
<td>5.8</td>
<td>3.9</td>
</tr>
<tr>
<td><strong>T&lt;sub&gt;max&lt;/sub&gt; [°C]</strong></td>
<td>210</td>
<td>220</td>
</tr>
</tbody>
</table>
Folded Core Technology
University of Stuttgart, Institute of Aircraft Design

Y. Klett, 2013
Variety of Folded Cores
Manufacture of CFRP Cores via Folding Technology

- Prepreg with release tapes
- Folding and forming in wooden mould (380 x 400 mm²)
- Curing + Postcuring at T = 130°C/3h + 210 °C/4.5h
- 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)
Core Structure and Joining after Siliconication

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

![Diagram of C/C-SiC Sandwich Geometry](image)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total thickness</td>
<td>[mm]</td>
<td>15</td>
</tr>
<tr>
<td>Skin thickness (0°/90°)</td>
<td>[mm]</td>
<td>1</td>
</tr>
<tr>
<td>Core height</td>
<td>[mm]</td>
<td>13</td>
</tr>
<tr>
<td>Core wall thickness (0°/90° and ±45°)</td>
<td>[mm]</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Fibre orientation in core:

- 0°/90°
- ±45°

N. Gottschalk 2015
Coupon Geometry and Test Set Up

4 Pt. Bending according to DIN 53239

L_A = 230
L_S = 75
b = 50
I = 360
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

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

- Core is increasing stiffness of sandwich structure
- Lighter core possible?
Comparison Sandwich Structure – Solid Panel

Sandwich panel offers:
- 80 times higher flexural stiffness
- 6 times higher load at fracture

Solid panel of same stiffness \( t_{\text{solid}} = 11 \text{ mm}; m_{\text{solid}} = 4 \times m_{\text{sandwich}} \)

\[ 5.7 \text{ kg/m}^2 \]
\[ 5.48 \text{ kg/m}^2 \]
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).
- C/C-SiC Sandwich design based on folded cores offer highly stiff and lightweight C/C-SiC structures.
Outlook

- Use of high performance skin materials.
- Lighter core materials by using lighter fabrics (245 \(\rightarrow\) 80 g/m\(^2\)).
- Grid / honeycomb core types with wall structures perpendicular to skins.
- Upscaling to praxis relevant sandwich structure (ca. 500 x 500 x 70 mm\(^2\)).
- Demonstrator.