Feasibility Study for C/C-SiC Sandwich Structures

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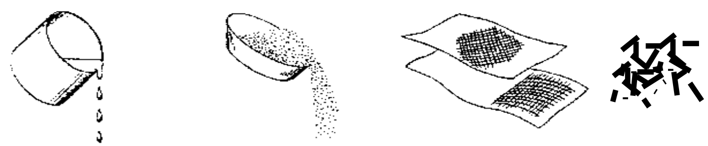
Outline

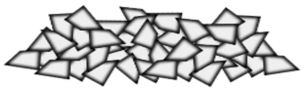
- C/C-SiC materials
- Motivation
- Manufacture of C/C-SiC sandwich structures via LSI
- Test results
- Summary and outlook

C/C-SiC Manufacture via Liquid Silicon Infiltration (LSI)

Precursor Additives Fibers



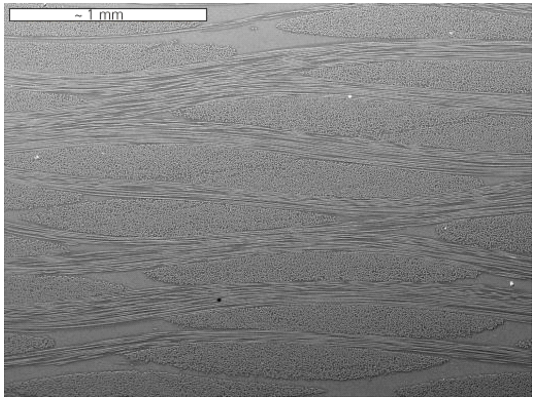
Silicon Granules



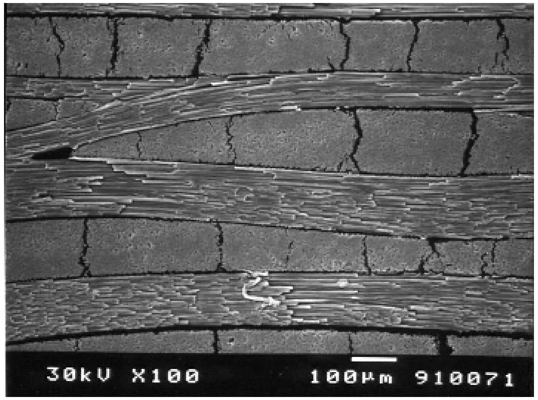
CFRP (Shaping)
T < 250 ºC

Pyrolysis
T > 900 ºC

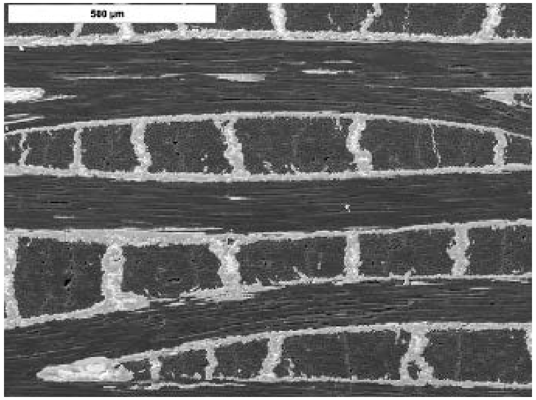
Siliconization
$Si + C \rightarrow SiC$
T > 1500 ºC



CFRP



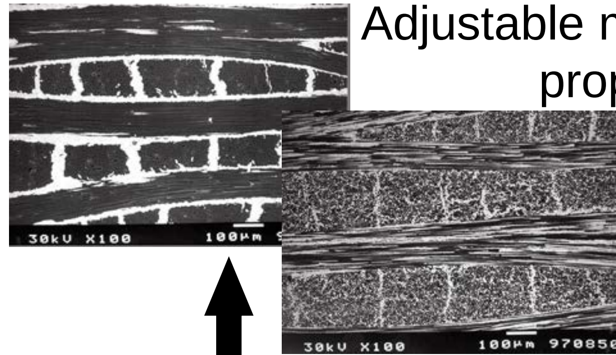
C/C



C/C-SiC

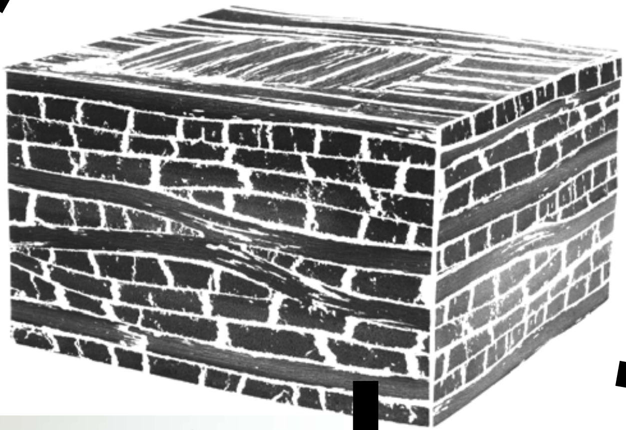
General Properties of C/C-SiC Materials

Thermal shock resistance

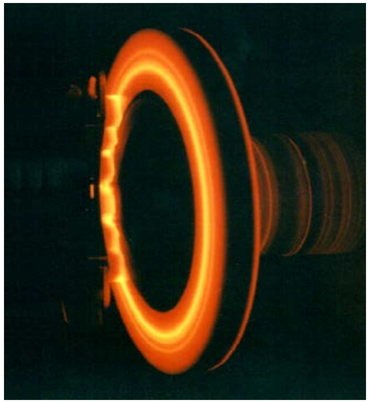


Adjustable microstructure / properties

Damage tolerance



Wear resistance
Low density



Low CTE

II : - 0.5 to 2.5 ppm

⊥ : 2 – 7 ppm

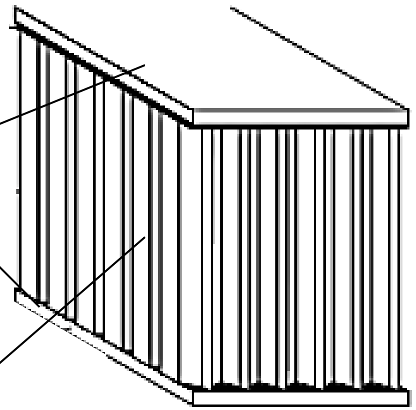
Internal oxidation protection

Sandwich Design

Sandwich Panel

Face skins

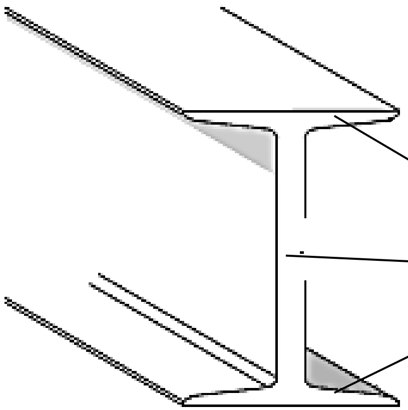
High tensile / compression strength and moduli



Core

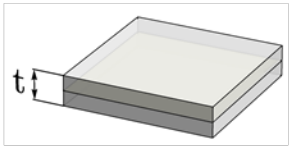
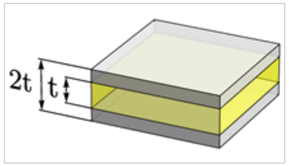
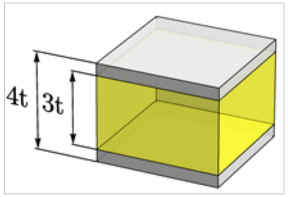
- Sufficient shear strength
- lightweight

I-Beam



Hexcel Composites, 2000;

Why Sandwich?

	Solid Material	Core Thickness t	Core Thickness 3t
			
Stiffness	1	7	37
Flexural Strength	1	3.5	9.2
Weight	1	1.03	1.06

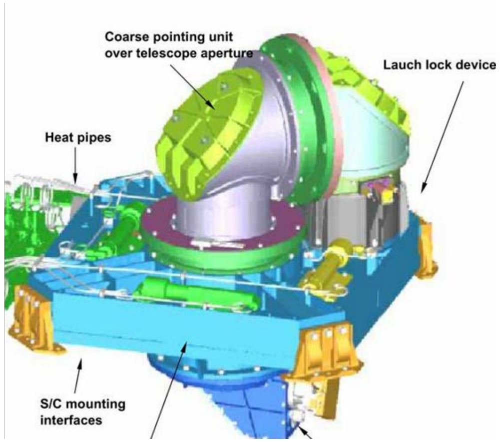
Hexcel Composites, 2000; Y.Klett 2013

Target Applications of C/C-SiC Sandwich Structures

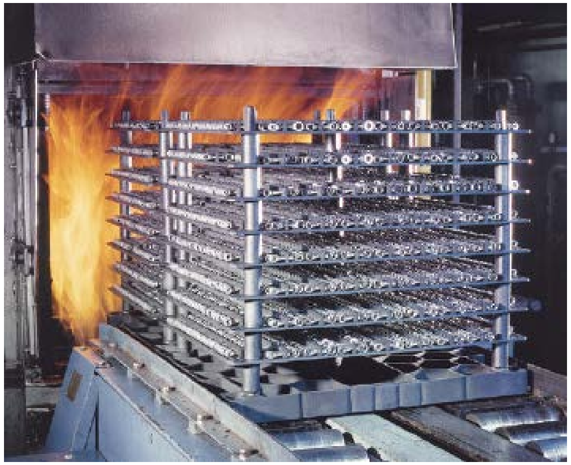
- Thermally stable telescope structures (CTE ≈ 0 ppm)
- Highly stiff and lightweight panels for satellite structures
- Charging carriers for high temperature furnaces

Others:

- Cooled structures for propulsion or TPS
- High temperature heat exchangers
- …

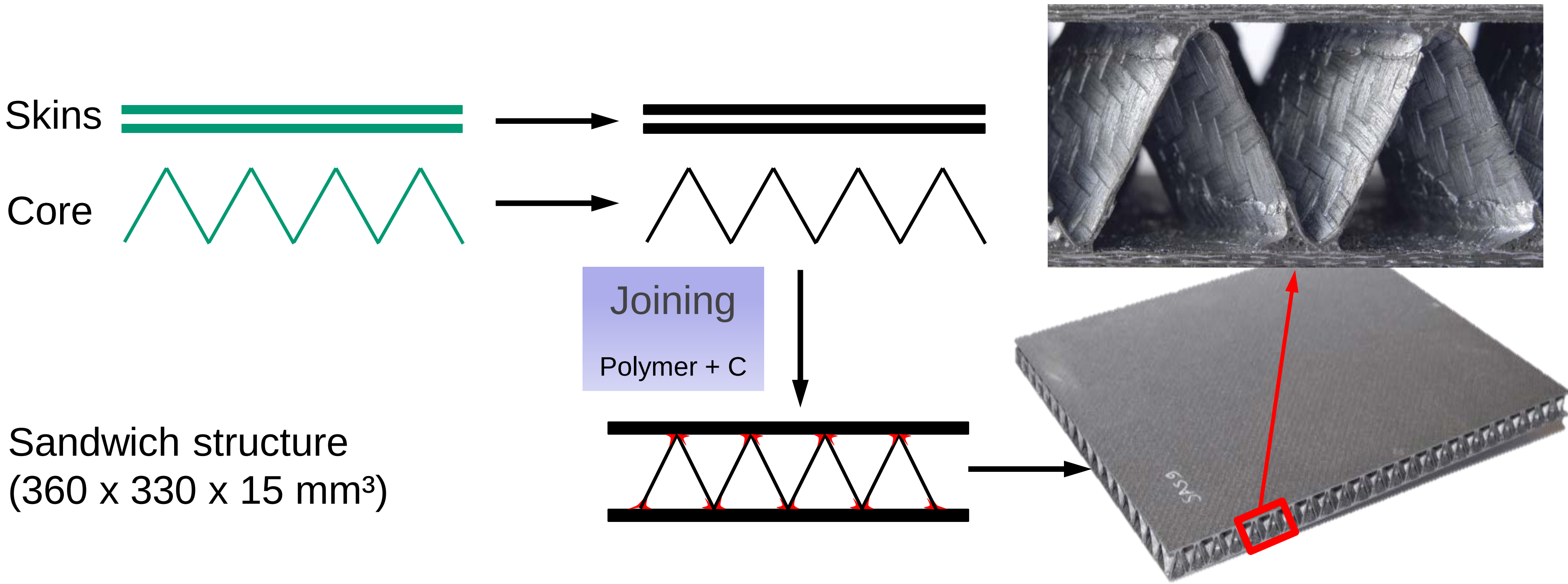


R. Barho, M. Schmid, 2003



Schunk Kohlenstofftechnik

Manufacture of C/C-SiC Sandwich Structures



Warm pressing — CFRP Preforms

Pyrolysis — C/C Preforms

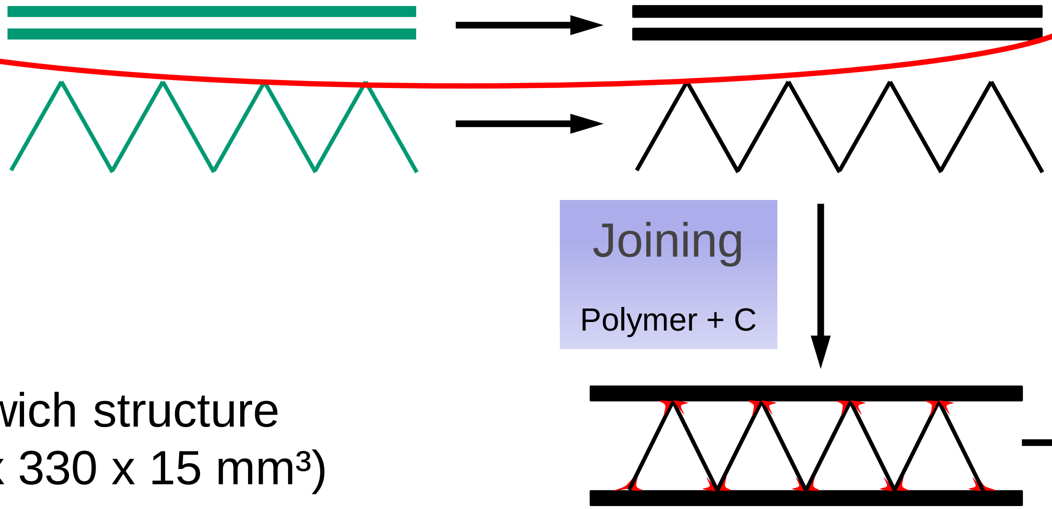
Siliconization — C/C-SiC Structure

Manufacture of C/C-SiC Sandwich Structures

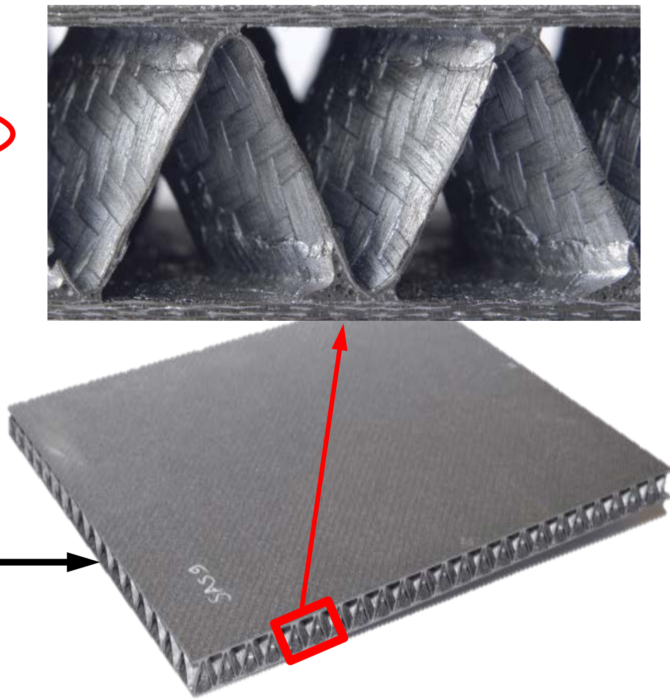
3 methods for manufacturing skin preforms

Skins

Core



Sandwich structure
(360 x 330 x 15 mm³)



Warm pressing
CFRP Preforms

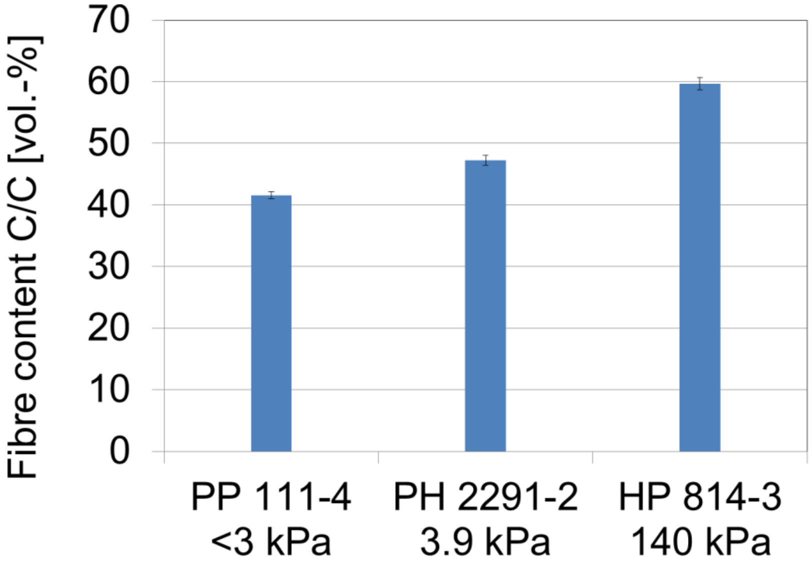
Pyrolysis
C/C Preforms

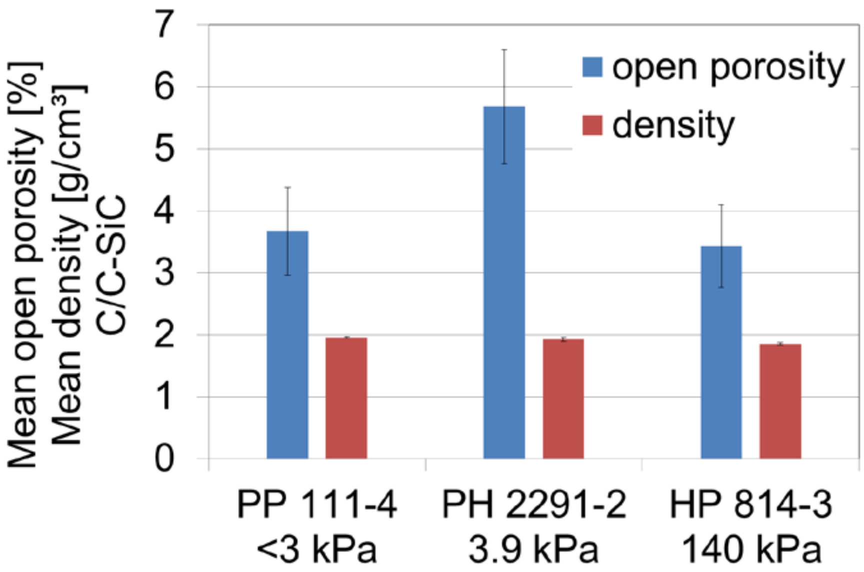
Siliconization
C/C-SiC Structure

Preform Manufacture

	Core	Skin Panel		
		PH 2291	HP 814	PP 111
Raw Material	Prepreg: C fibre fabric (245 g/m²) + Phenol-Resol			
Lay up	1 layer 0°/90° and ±45°	3 layers 0°/90°		
CFRP / C/C preform manufacture	Folding + Warm pressing	Warm pressing		Direct pyrolysis of prepreg
p_{max} [kPa]	5.8	3.9	140	< 3
T_{max} [°C]	220	220		900

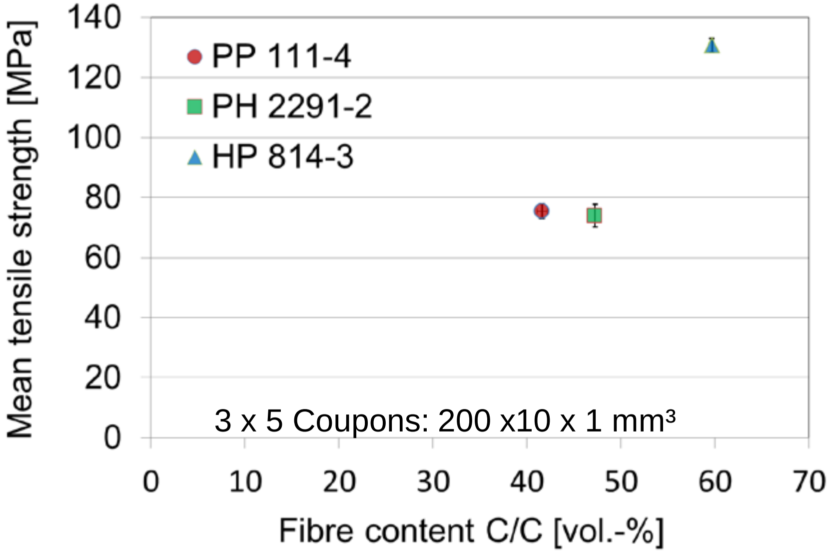
Properties of Skin Material Variants

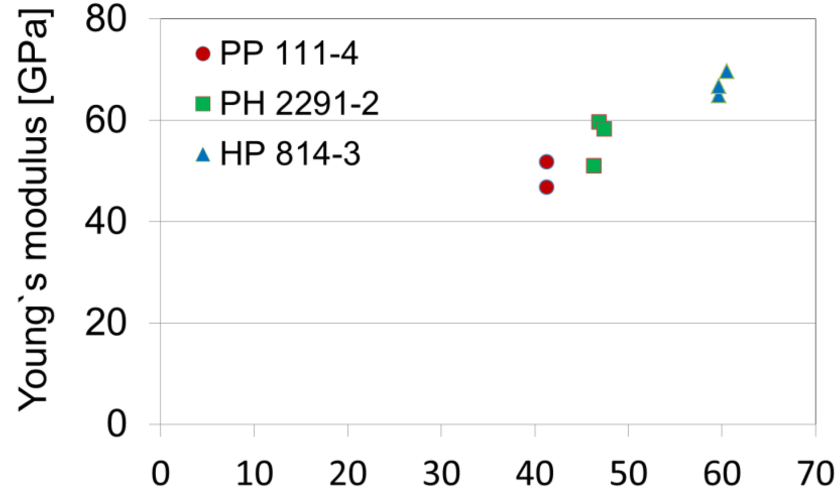




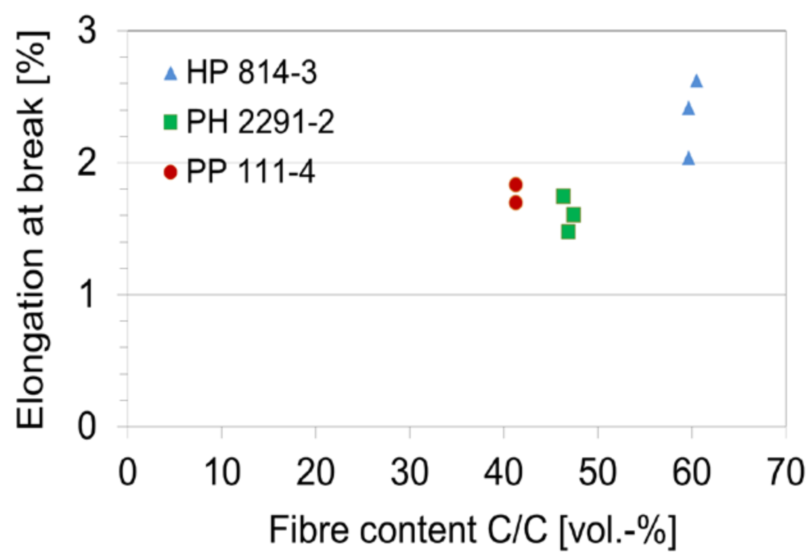
- Fibre volume content of C/C preform increases with laminate pressure
- No significant difference in density.
- Slightly higher open porosity of C/C-SiC based on low pressure CFRP preform.

Tension Properties of Skin Material (DIN 658-1)



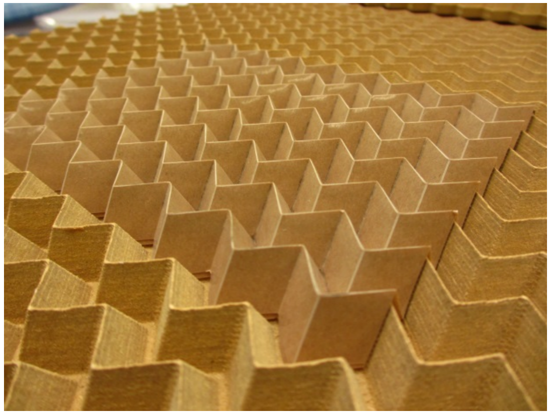


- Highest performance of materials based on highly pressurized CFRP with high fibre content
- PH material selected for sandwich skins due to homogeneous siliconization

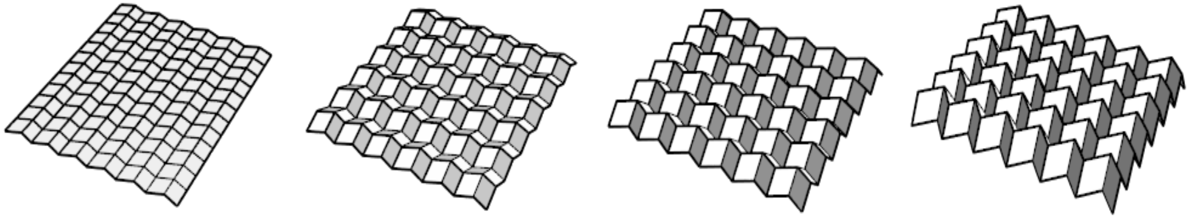


Manufacture of Cores via Folding Technology

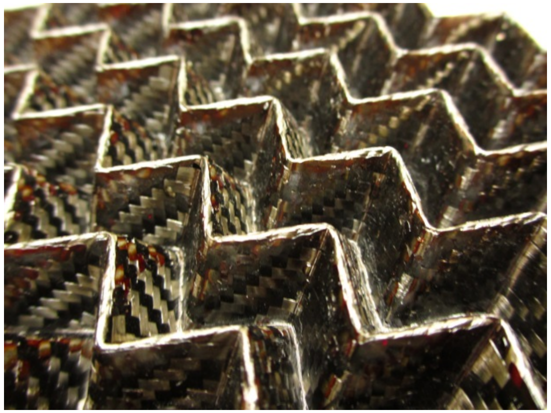
- Prepreg with release tapes
- Folding and forming in wooden mould (380 x 400 mm²)
- Curing/ Postcuring at T = 130 / 210 °C
- CFRP fold core (360 x 330 x 13 mm³)



N. Gottschalk 2015

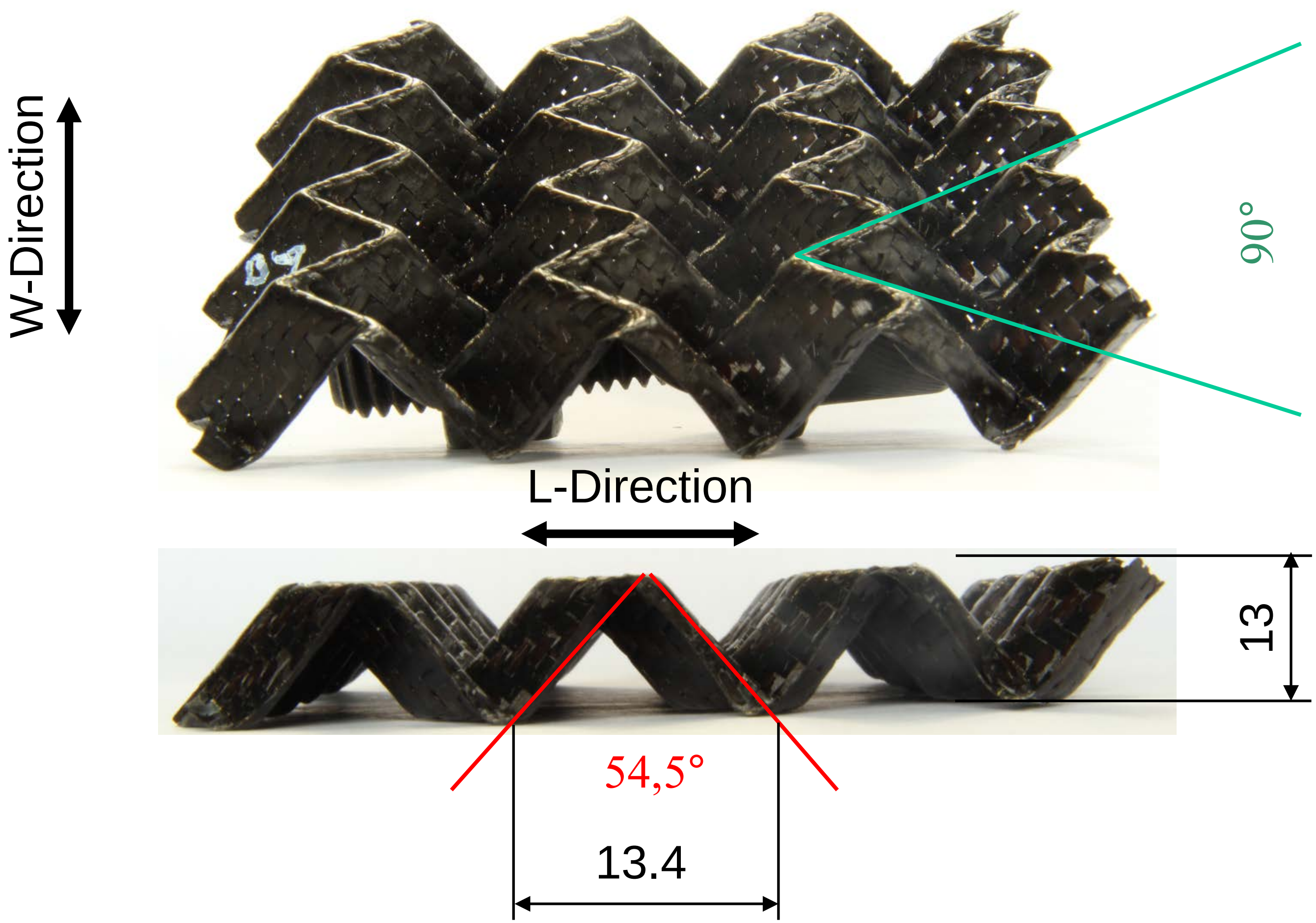


Y. Klett, 2013



N. Gottschalk 2015

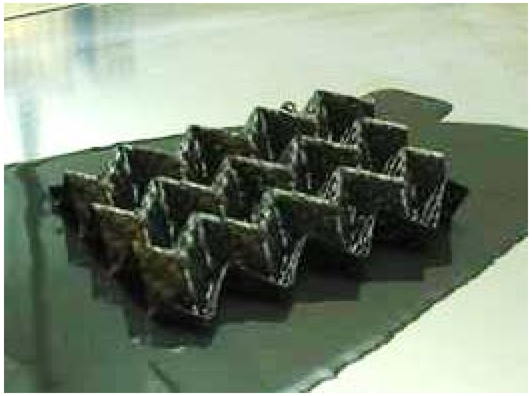
Folded Core - Geometry

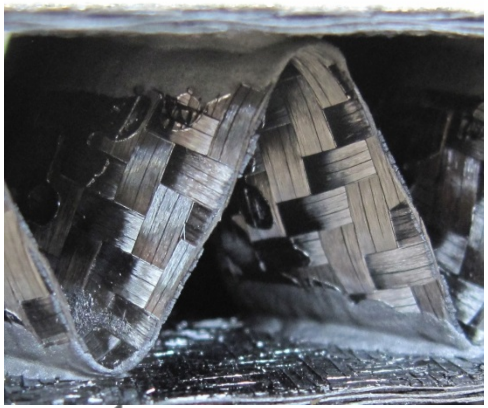


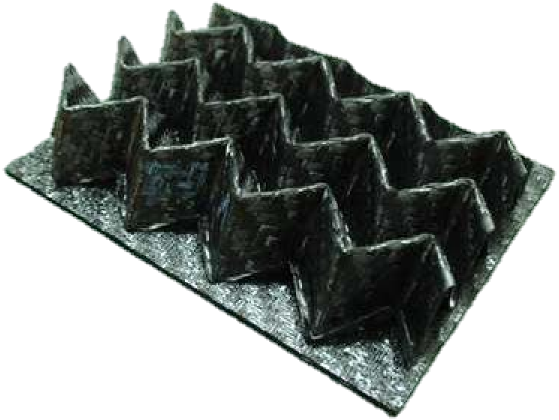
Joining

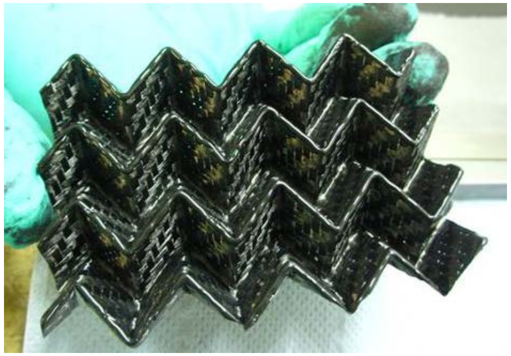
- Joining paste: Phenolic resin (JK 60) + C particles (PC 40; < 45 µm)
- C/C-core preform dipped in joining paste with constant film thickness (3 mm)
- Curing of joining paste (220 °C / 4h)
- Joining of second skin

→ C/C sandwich preform (360 x 330 x 15 mm^3)







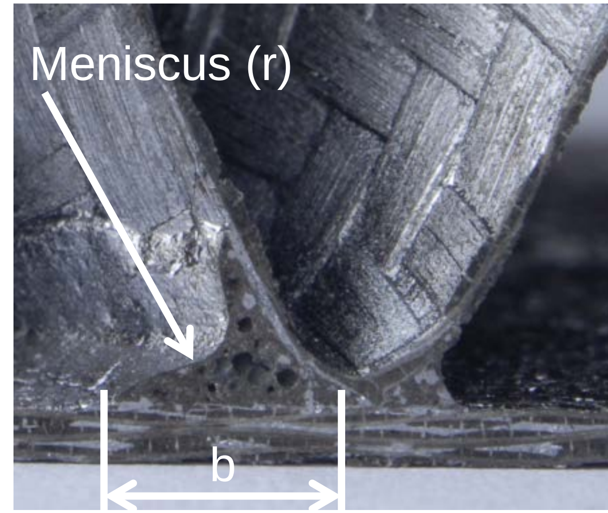


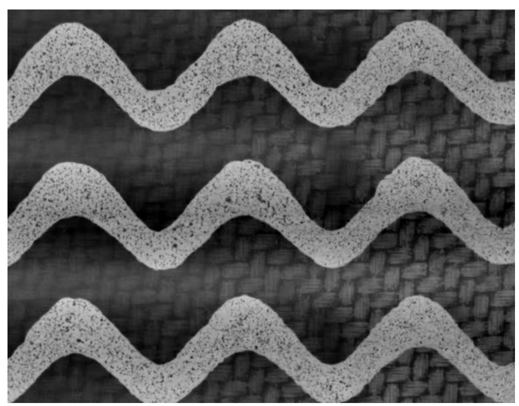
N. Gottschalk 2015

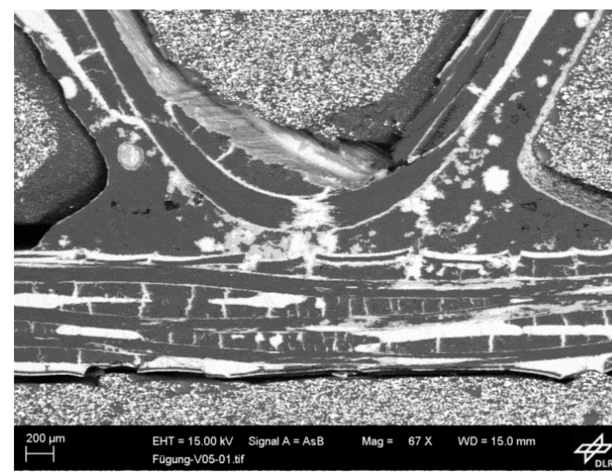
Results – Core Structure and Joining

- Single layer core material shows characteristic microstructure
- C/C-SiC core weight ≈ 100 kg /m³
- C-rich joining after siliconization

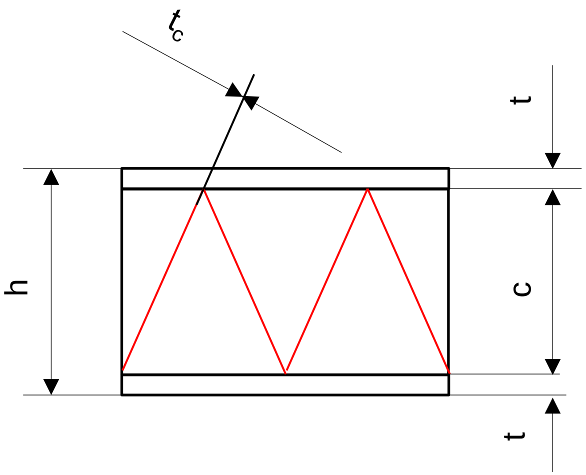
  (71% C;18% SiC; 11% Si)
- Homogeneously joined contact lines







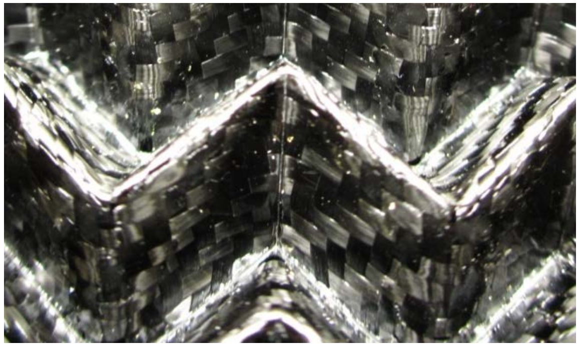
Sandwich Geometry



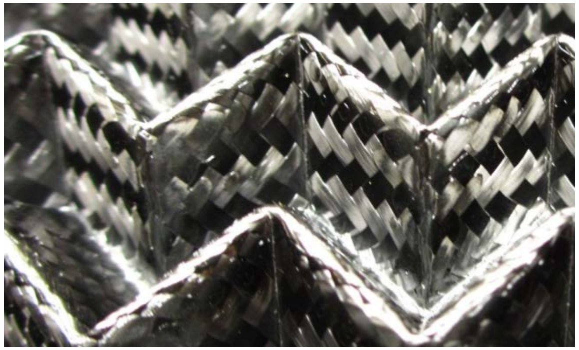
		[mm]
Total thickness	h	15
Skin thickness (0°/90°)	t	1
Core height	c	13
Core wall thickness (0°/90° and ± 45°)	t_c	0.3

Fibre orientation in core

0°/90°



±45°



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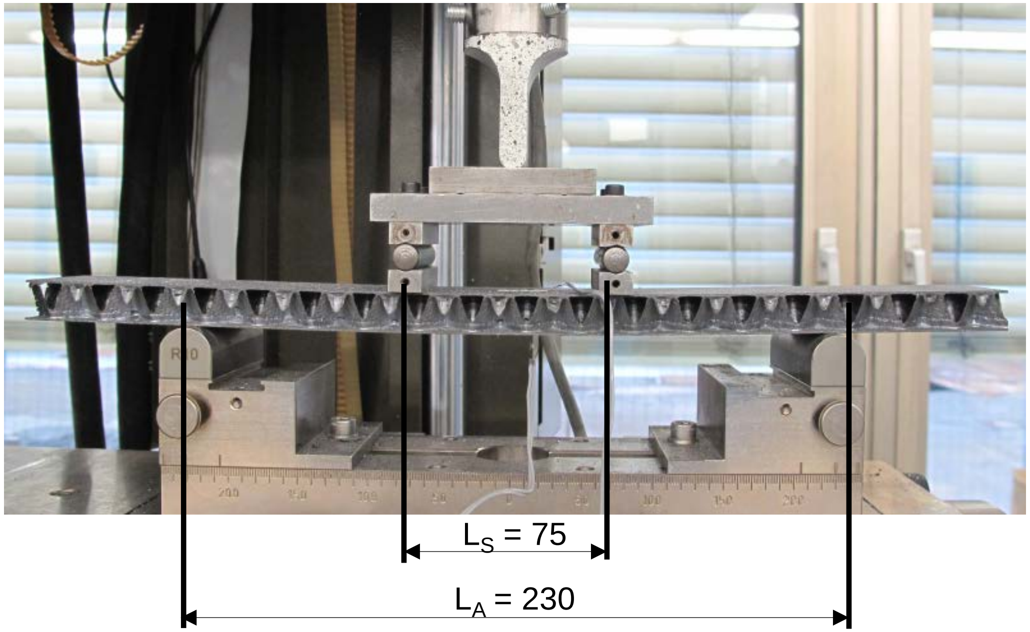
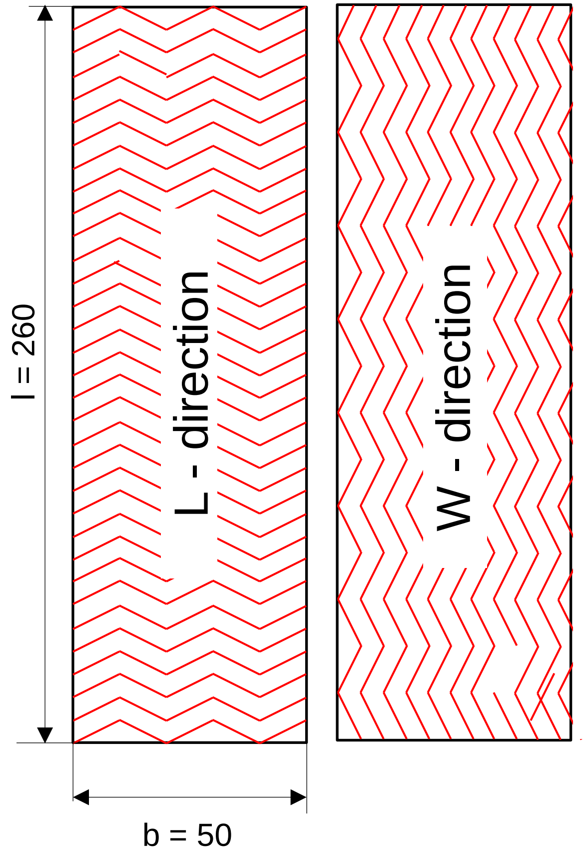
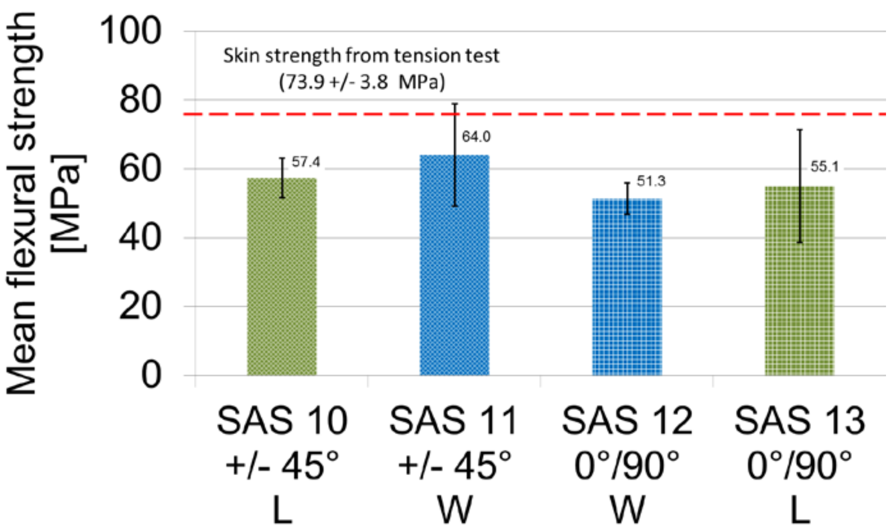
Coupon Geometry and Test Set Up

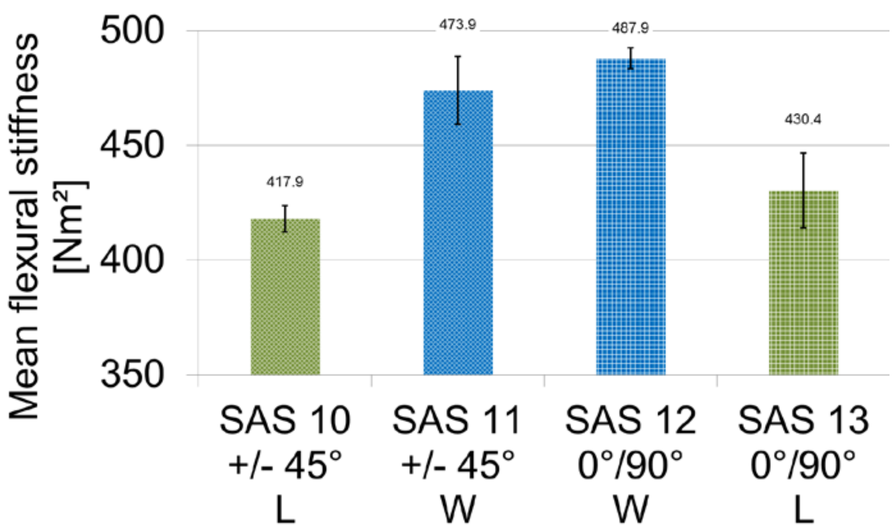
4 Pt. Bending according to DIN 53239





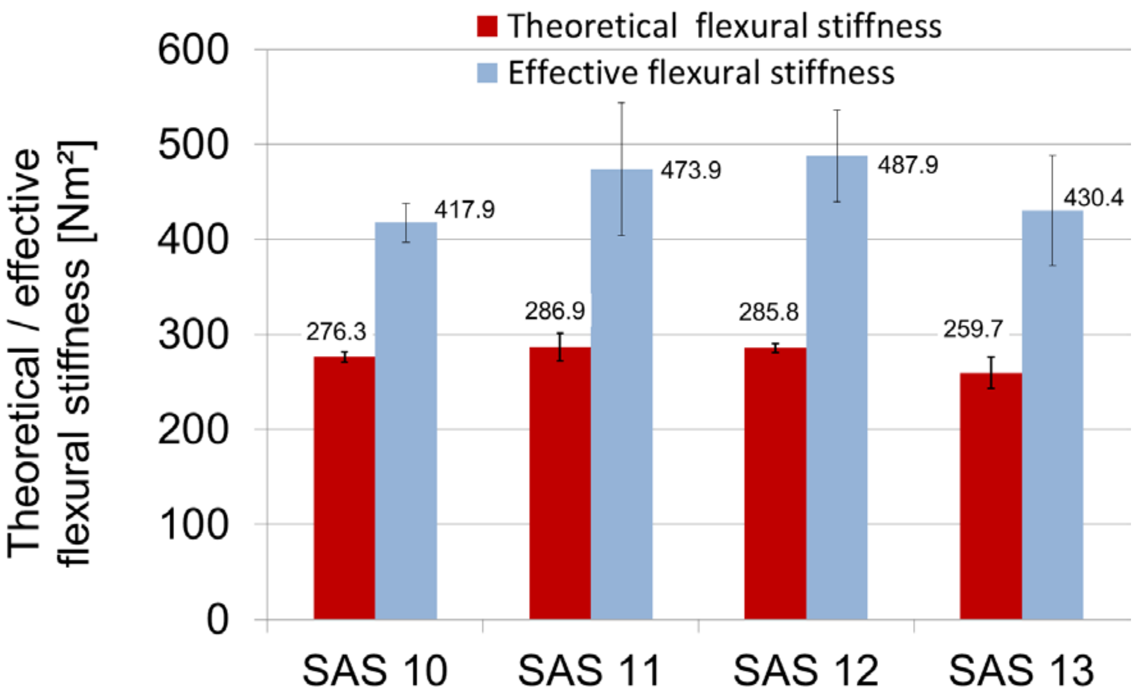
Results-Bending of Sandwich Structures





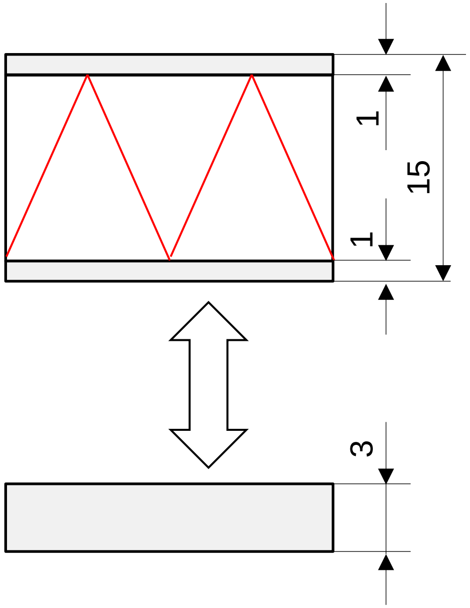
- Failure by tension fracture of lower skin
  (2 coupons out of 20 show shear failure of core)
- Load factor for the skins > 70 %
- Highest Stiffness in W-direction (joining lines II to sample length)

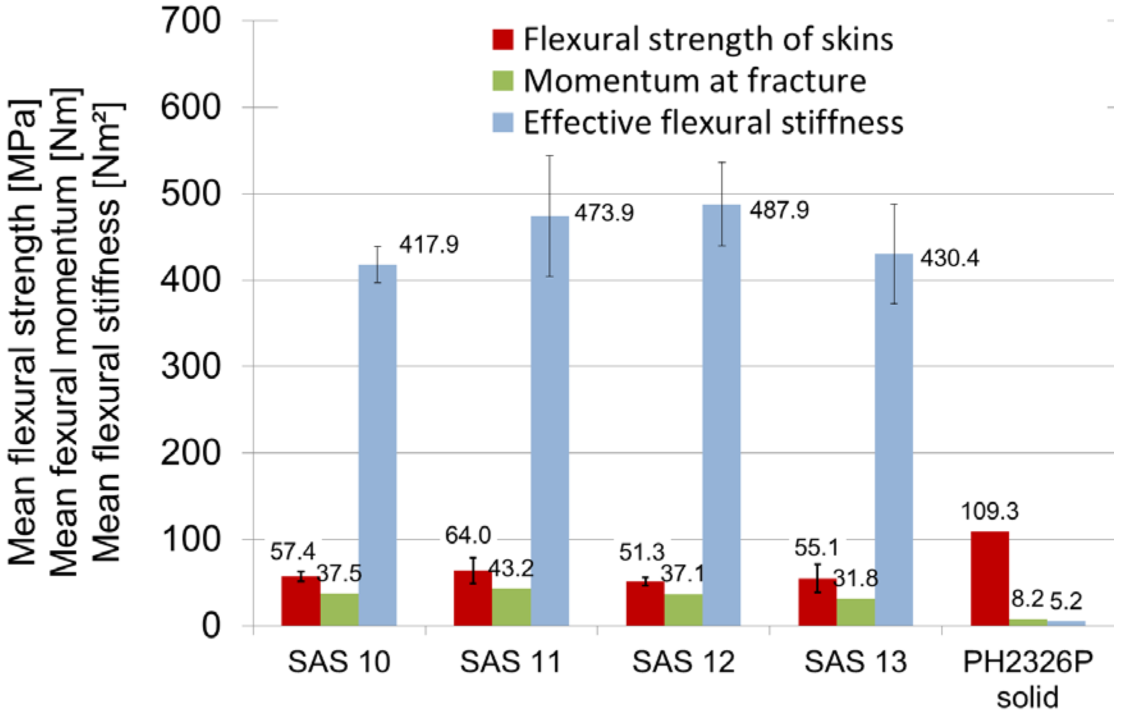
Sandwich Effectivity



- 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

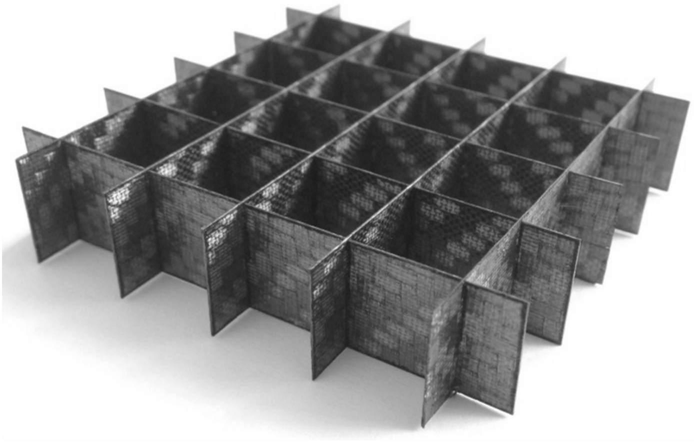
Summary

- 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.

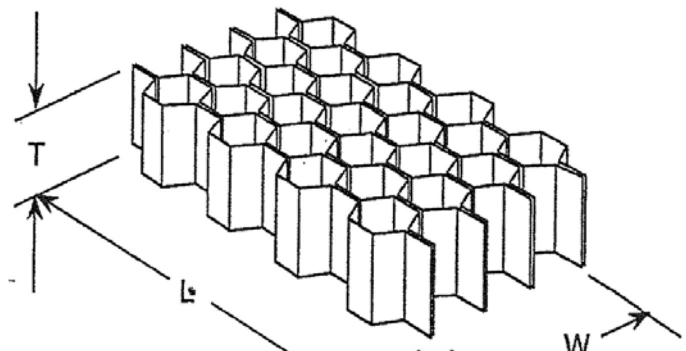
Outlook

- 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.

Grid core



Honeycomb core

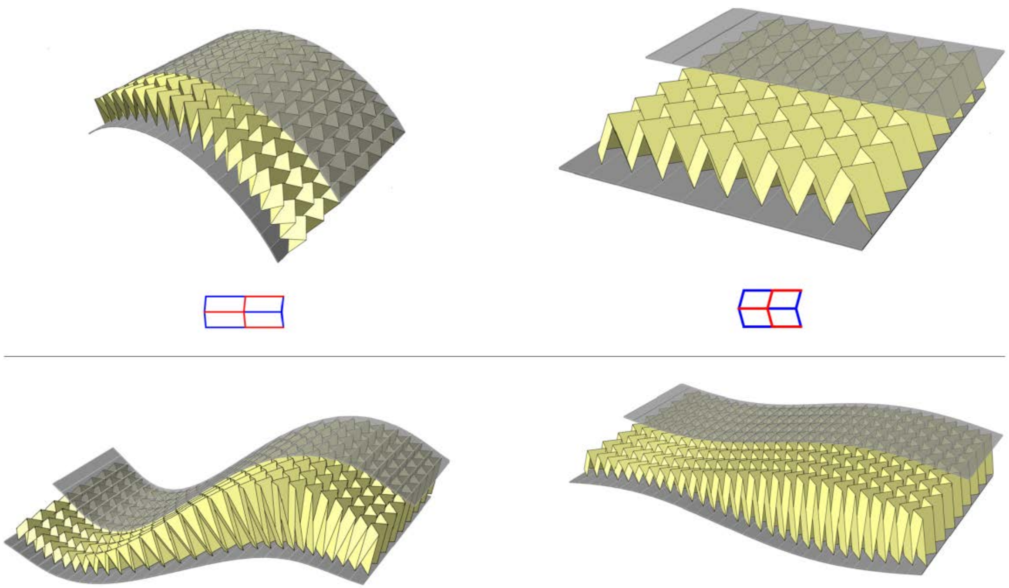


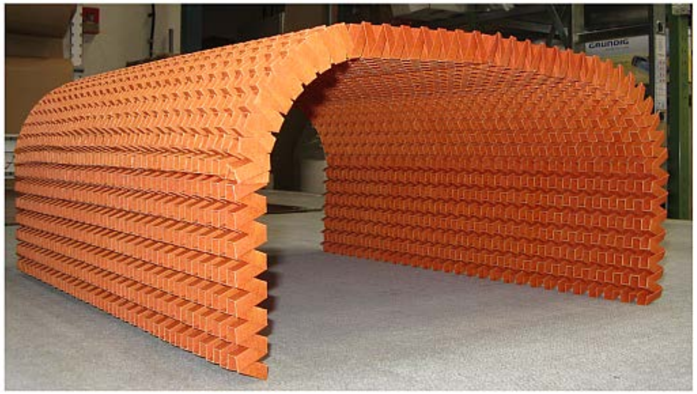
Source: Hexcel

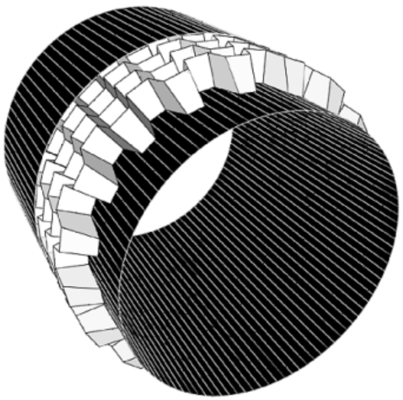
Thank you for your attention!

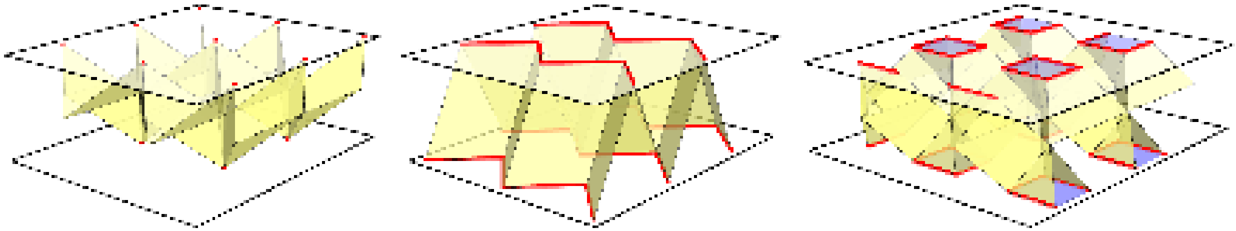
DLR

Manufacture of Cores via Folding Technology









Y. Klett,2013