Manufacture and Mechanical Properties of C/C-SiC Sandwich Structures

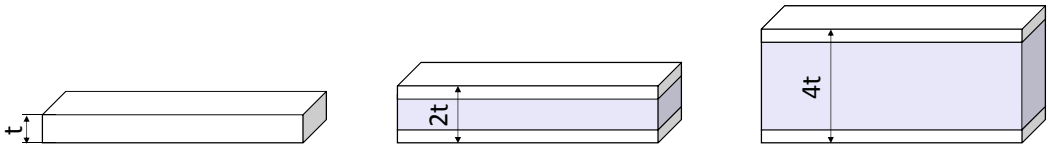
Bernhard Heidenreich[1], Harald Kraft[1], Nathan Bamsey[2], Yuan Shi[1], Miguel Such-Taboada[2], Dietmar Koch [3]

[1] Institute of Structures and Design, German Aerospace Center, Stuttgart, Germany
[2] ESA / ESTEC, Materials Technology Section TEC-MSP, Noordwijk, The Netherlands
[3] Institute of Materials Resource Management MRM, University of Augsburg, Germany

Content

- Introduction
- Manufacture of C/C-SiC sandwich structures
- Shear test
- Out of plane compression tests
- Summary

Sandwich Design for Lightweight Structures

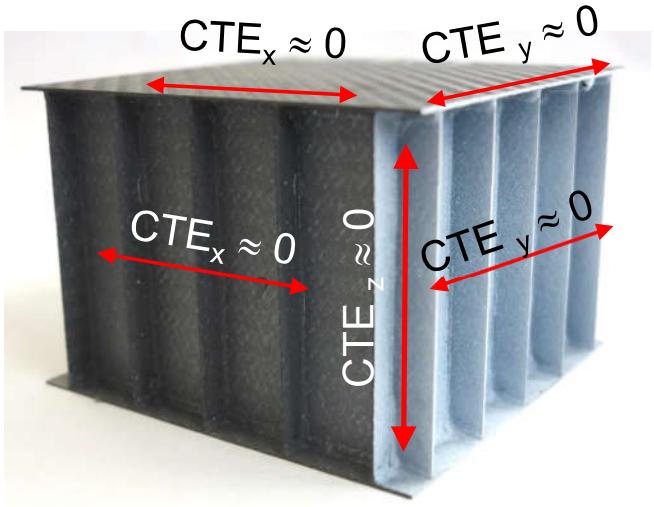


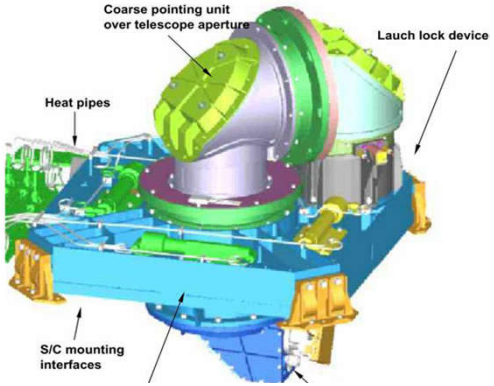
Flexural Stiffness	1	7	37
Flexural strength	1	3.5	9.2
Weight	1	1.1	1.2

Hexcel Composites, 2000; Y.Klett 2013

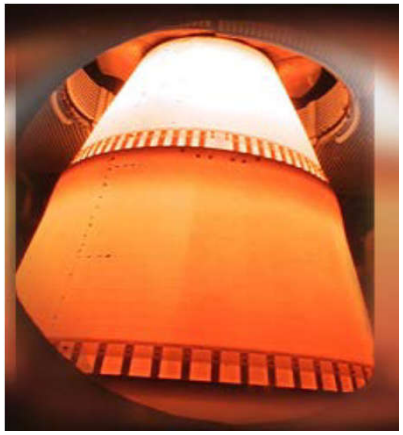
Target Application Areas for C/C-SiC Sandwich

- Thermally stable optical benches and telescope structures (CTE ≈ 0 ppm)
- Thermal protection systems and control surfaces (e.g. body flaps) for reentry space vehicles
- Internally cooled hot structures for propulsion systems
- Charging carriers for high temperature furnaces

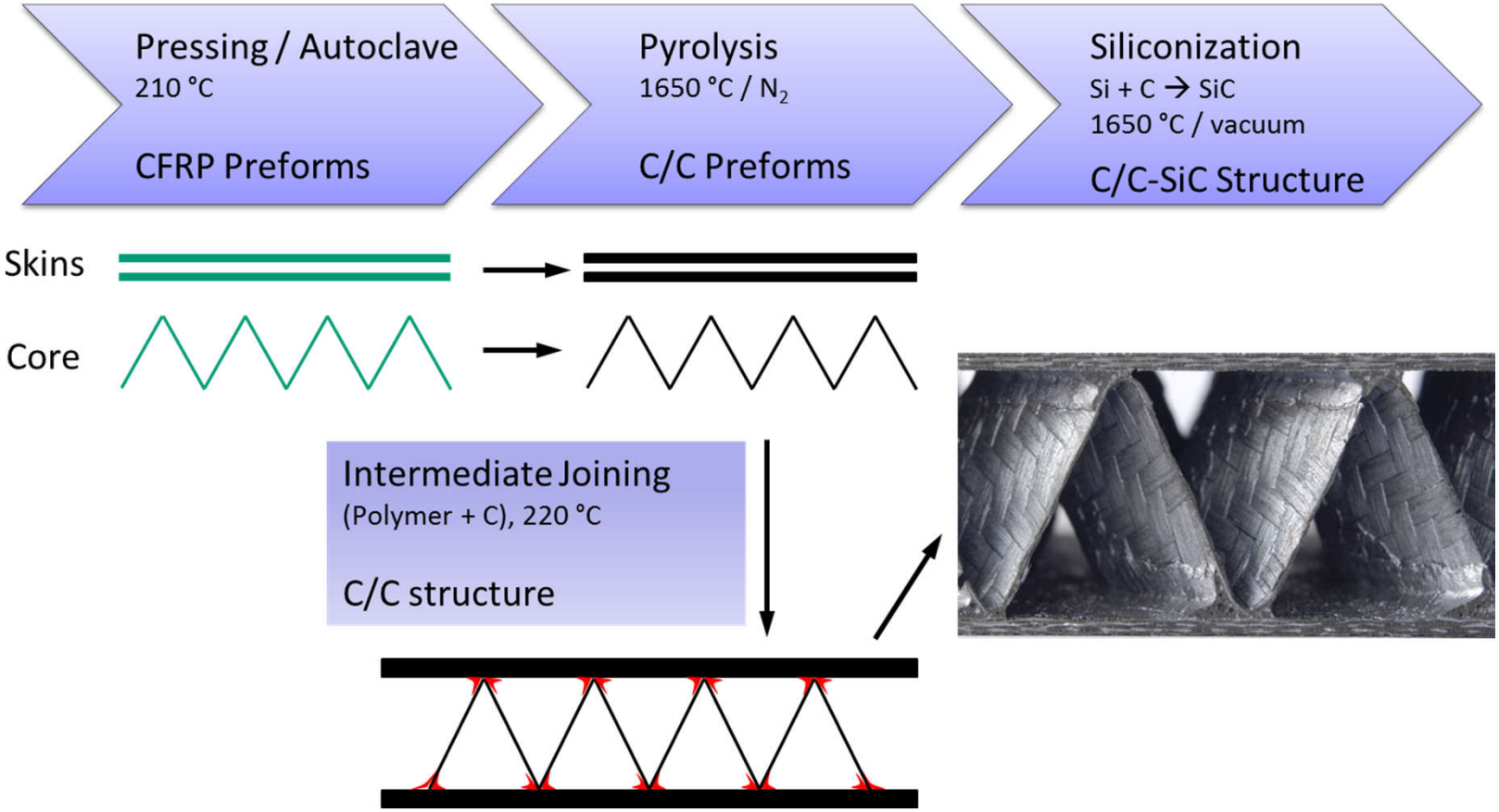




Quelle: ESA

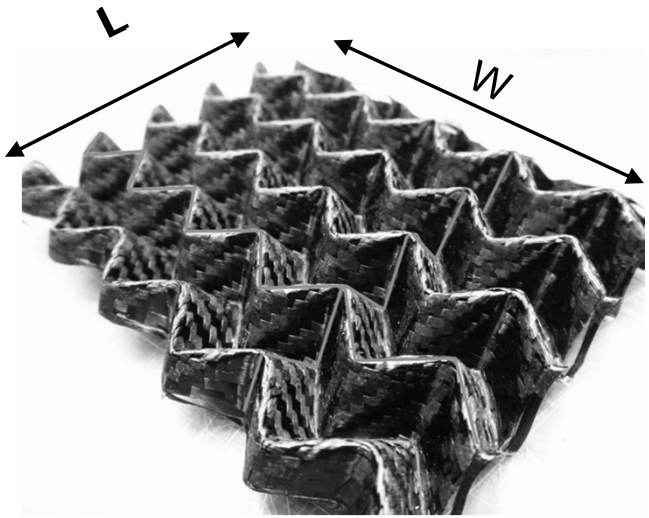


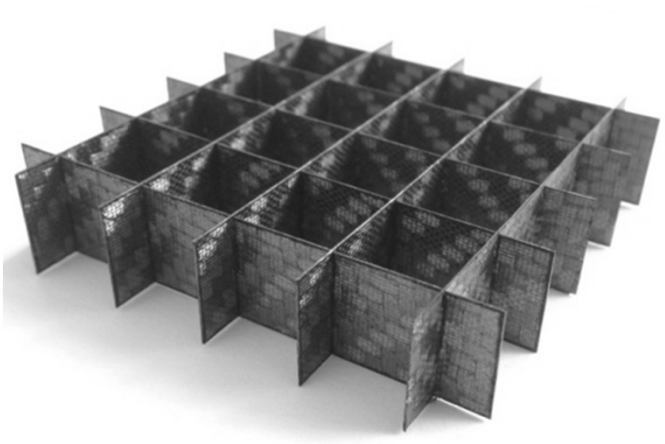
Manufacture of All C/C-SiC Sandwich Structures

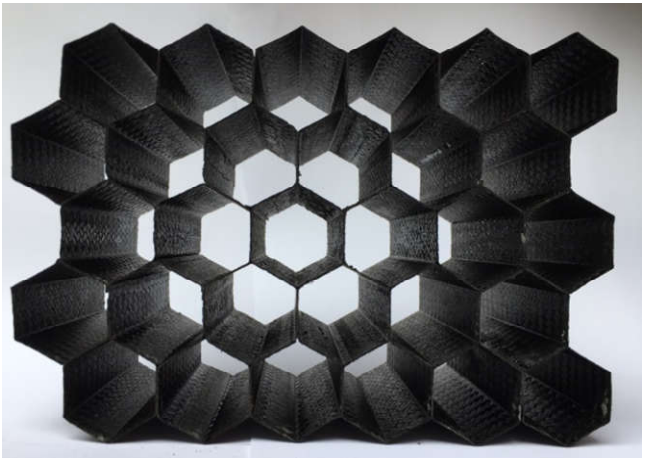


Core Types

Fold core (FC)	Grid core (GC)	Honeycomb core (HC)



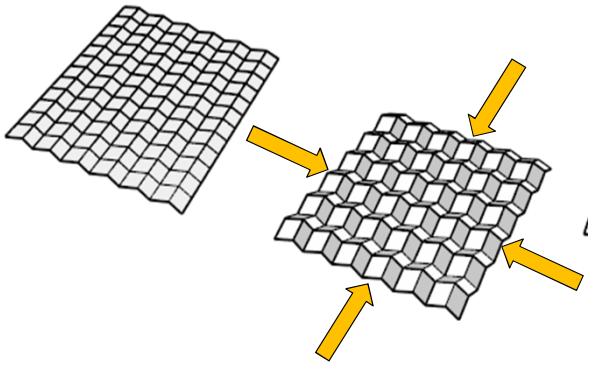




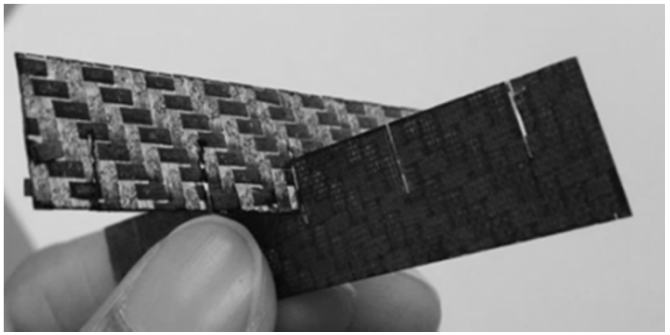
C/C preform based on 1 or 2 layer of prepreg (C Fabric: HTA 40, 6K, twill, 245 g/m² + phenolic rein)

Core Manufacture

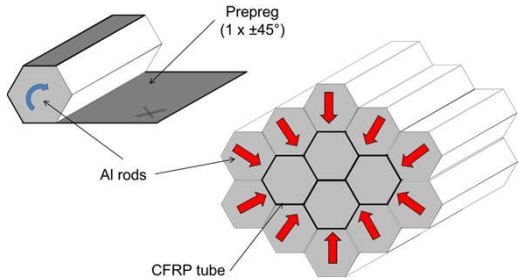
Fold core
(FC)



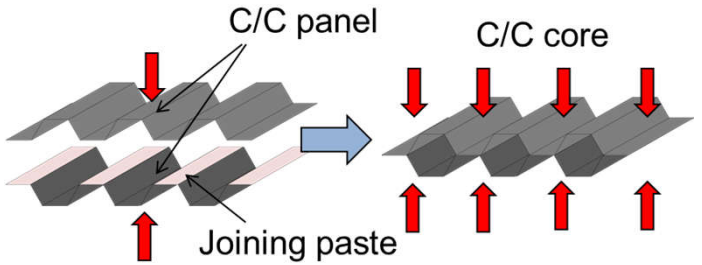
Grid core
(GC)



Honeycomb core based on Tubes
(HCT)



Honeycomb core based on panels
(HCP)



Shear Testing (DIN 53 294 / ASTM D 4255)

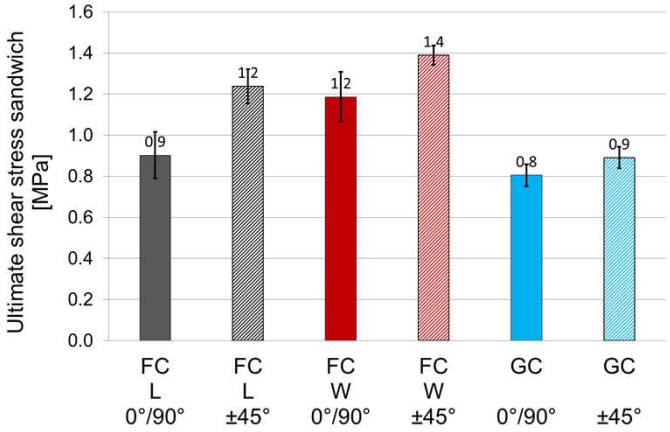
- Sample size: 73 x 50 x 15 mm³; core height c = 13 mm
- Two samples glued to Al-bars (pure shear load)

			Fold core				Grid core	
Core type			FC	FC	FC	FC	GC	GC
Core orientation			L	L	W	W	-	-
Fibre orientation in web			0°/90°	±45°	0°/90°	±45°	0°/90°	±45°
Cell width	w	[mm]	16				12	
Core density	ρ_c	[kg/m³]	90				74.1	
Core wall thickness	t_c	[mm]	0.3					

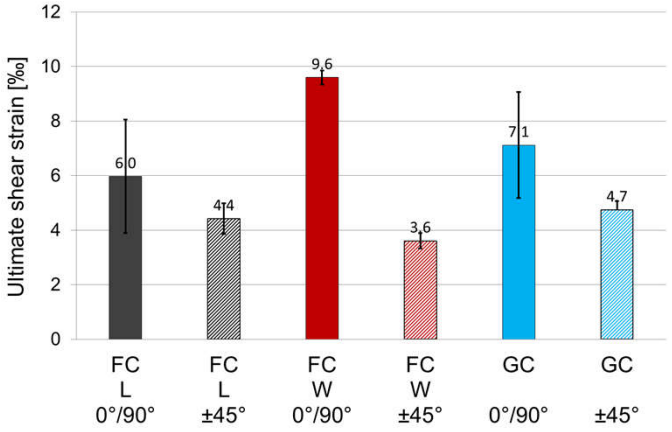
ASTM D 4255 / DIN 53 294

Shear Properties of Sandwich

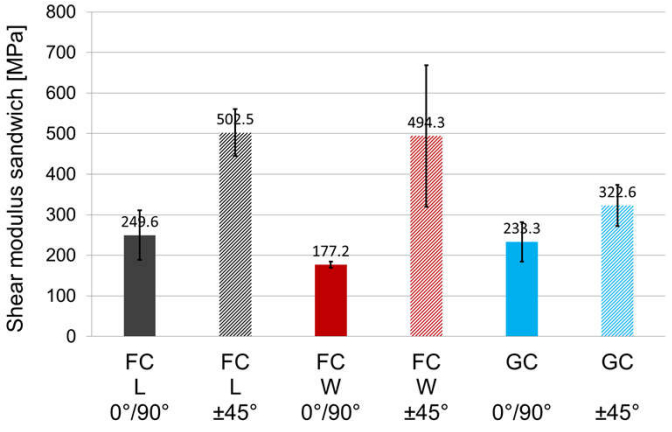
Strength



Strain



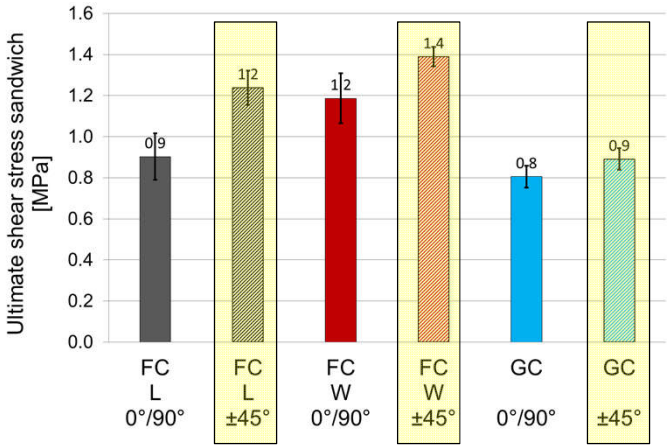
Modulus



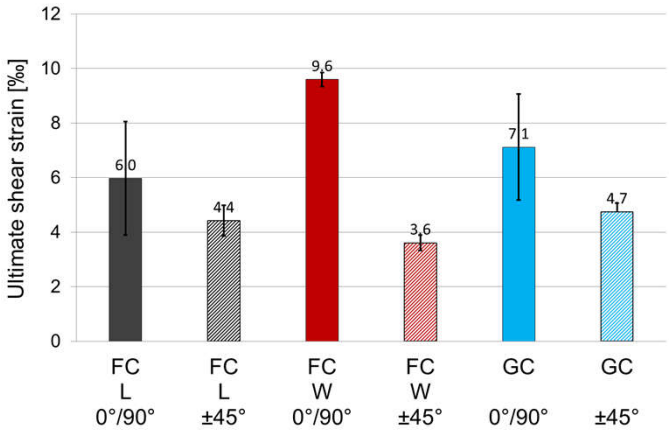
- FC offers higher properties compared to GC
- Fibre orientation of ± 45° leads to 44% higher shear strength (12 - 30 %) and modulus (40 – 280 %)
- Fibre orientation of 0° / 90° leads to higher shear strain (36 - 260 %)

Shear Properties of Sandwich

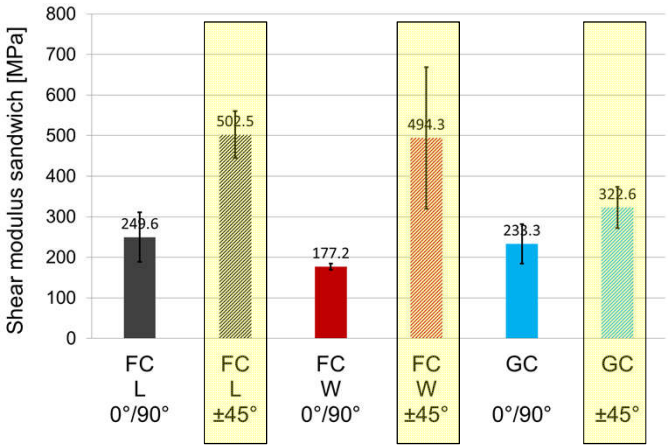
Strength



Strain



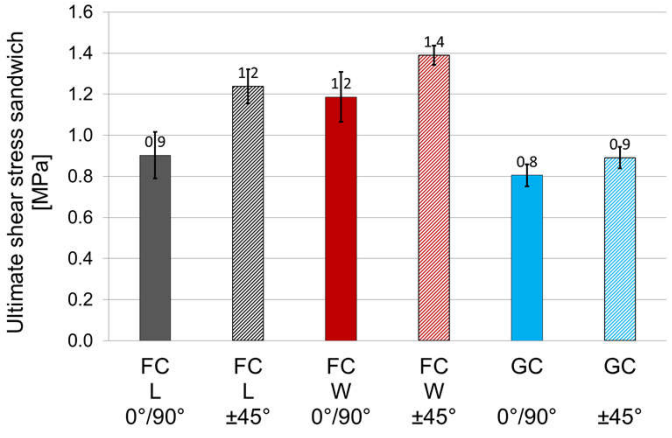
Modulus



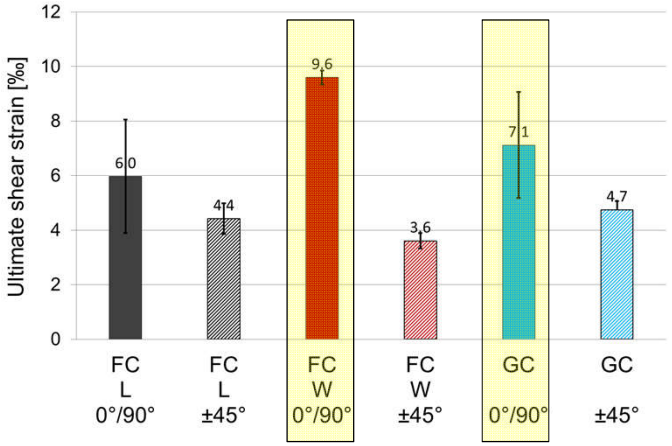
- FC offers higher properties compared to GC
- Fibre orientation of ± 45° leads to 44% higher shear strength (12 - 30 %) and modulus (40 – 280 %)
- Fibre orientation of 0° / 90° leads to higher shear strain (36 - 260 %)

Shear Properties of Sandwich

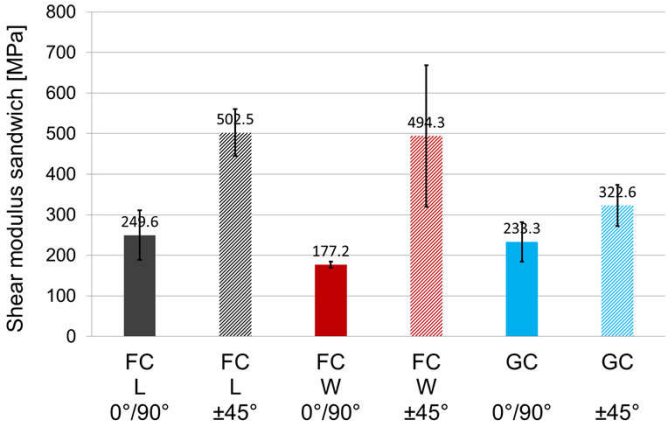
Strength



Strain

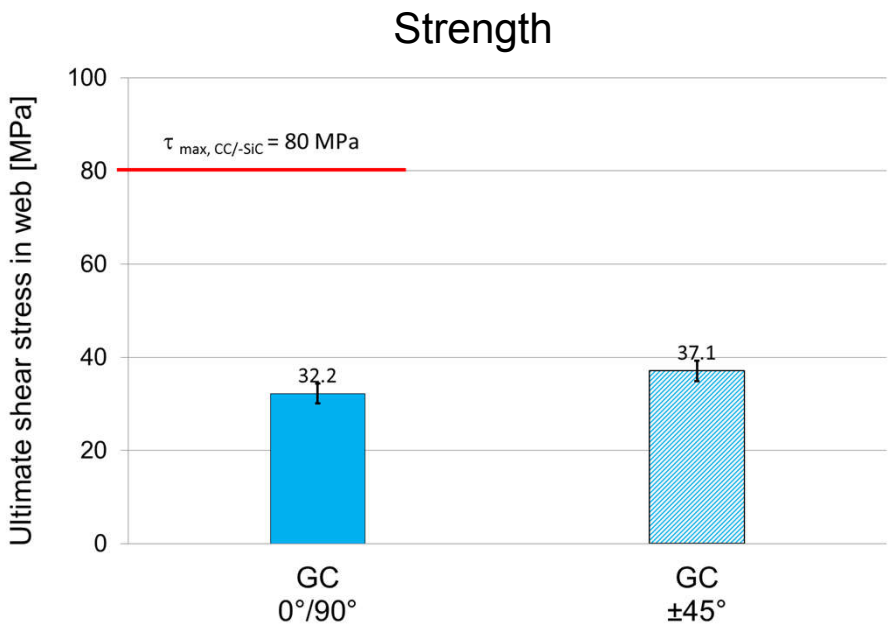


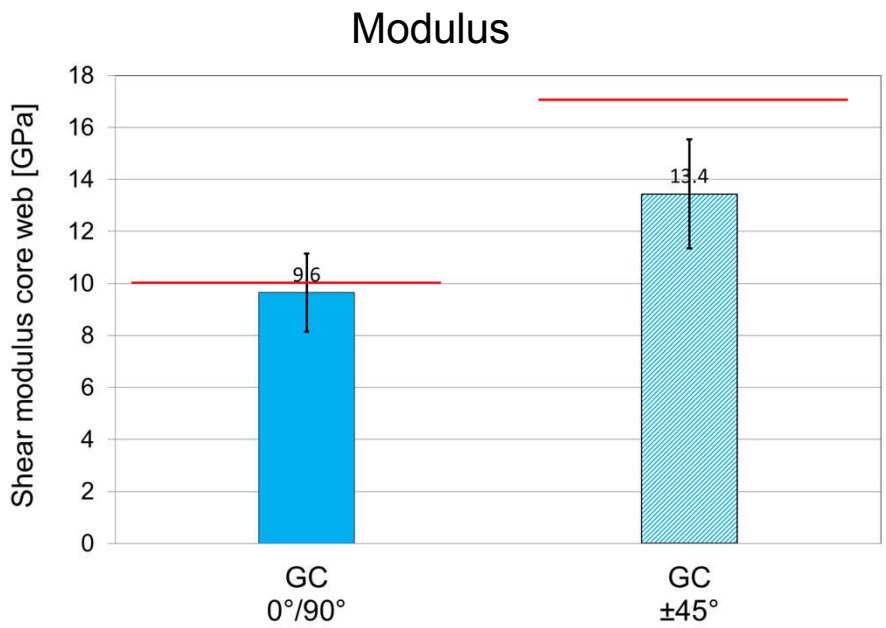
Modulus



- FC offers higher properties compared to GC
- Fibre orientation of ± 45° leads to 44% higher shear strength (12 - 30 %) and modulus (40 – 280 %)
- Fibre orientation of 0° / 90° leads to higher shear strain (36 - 260 %)

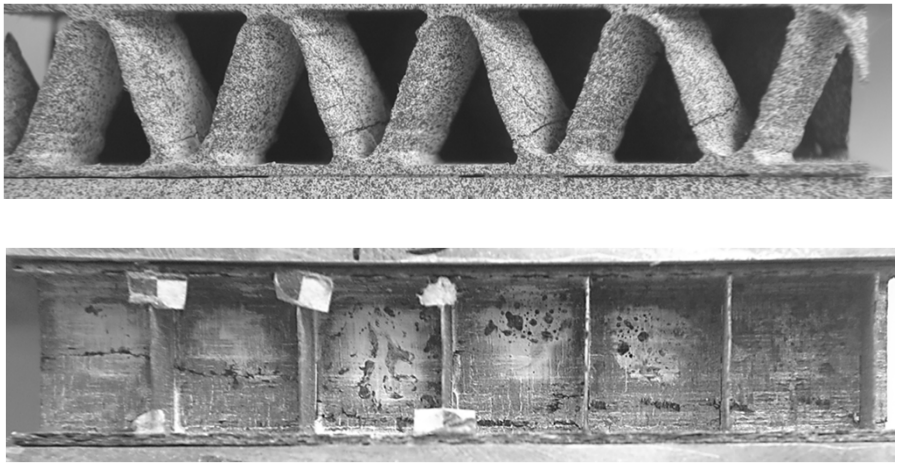
Shear Properties of Web (GC)

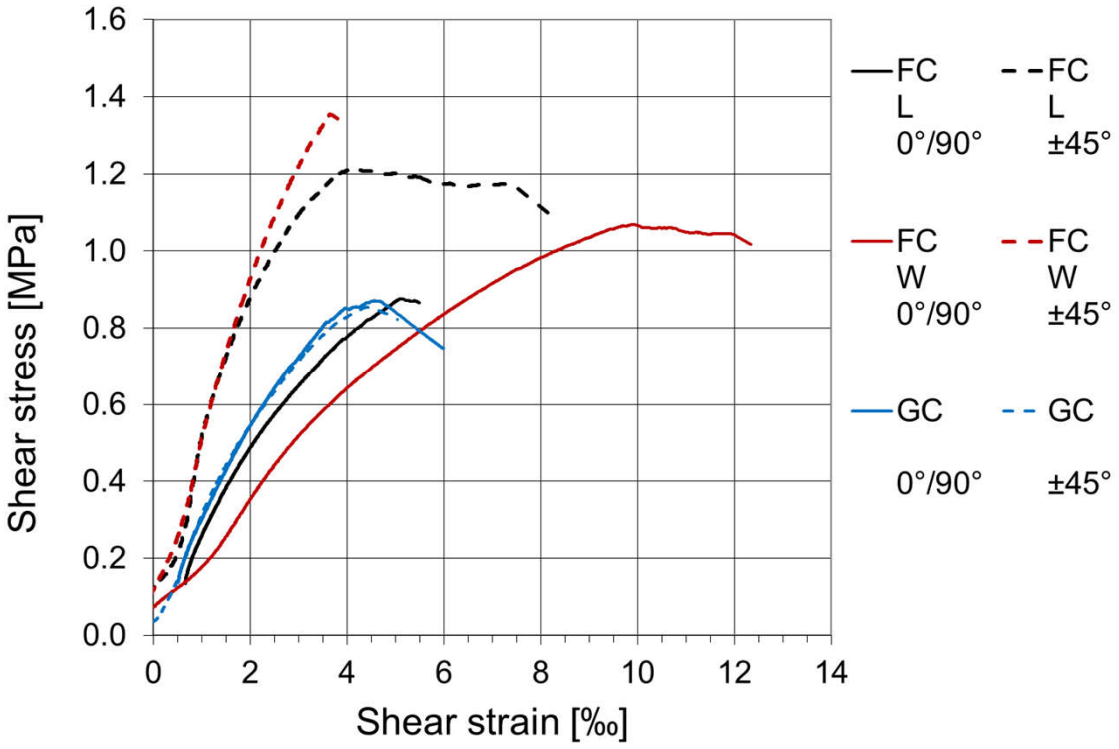




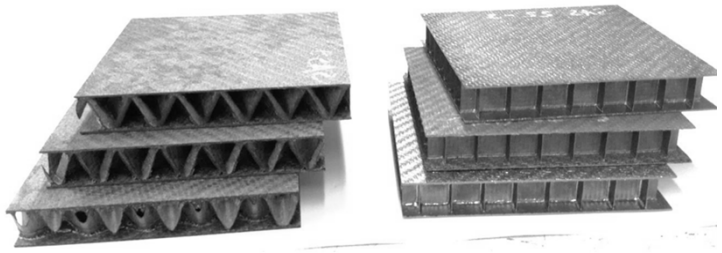
- Ultimate shear stress and mdulus of GC webs below C/C-SiC material properties due to buckling / slits
- Fibre orientation of ± 45° offers 15 % / 44% higher shear strength / modulus (as expected)

Stress / Strain Behaviour and Failure Mode





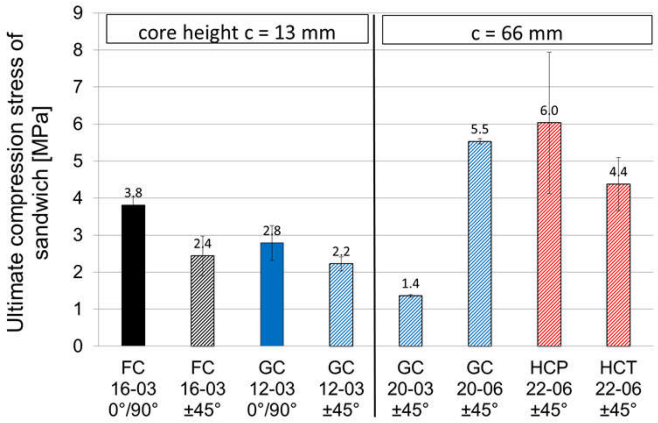
Compression Testing (DIN 53 291)



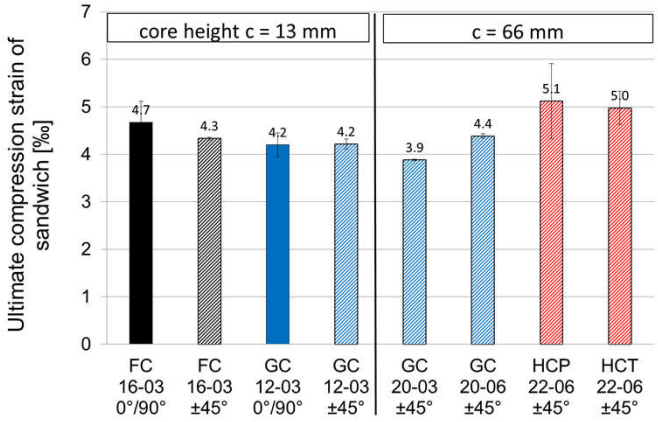
			Fold core		Grid core		Grid core		Honeycomb core	
Core type			FC	FC	GC	GC	GC	GC	HCP	HCT
Cell width - core wall thickness		[mm]	16-03		12-03		20-03	20-06	22-06	
Fibre orientation in web			0°/90°	±45°	0°/90°	±45°	±45°		±45°	
Core density	ρ_c	[kg/m³]	90		74		45	100	131	100
Core height	c	[mm]	13				66			

Compression Properties

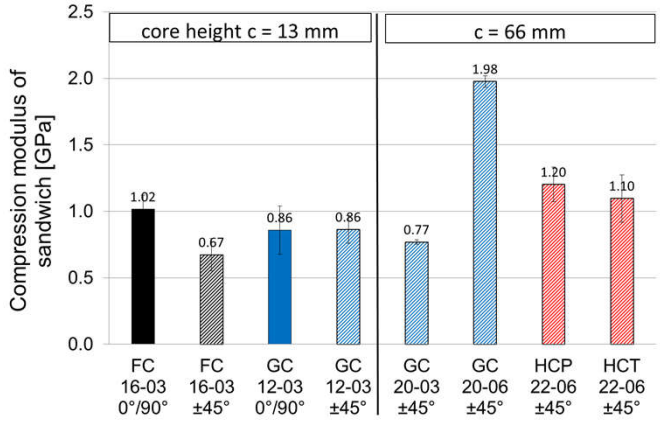
Strength



Strain



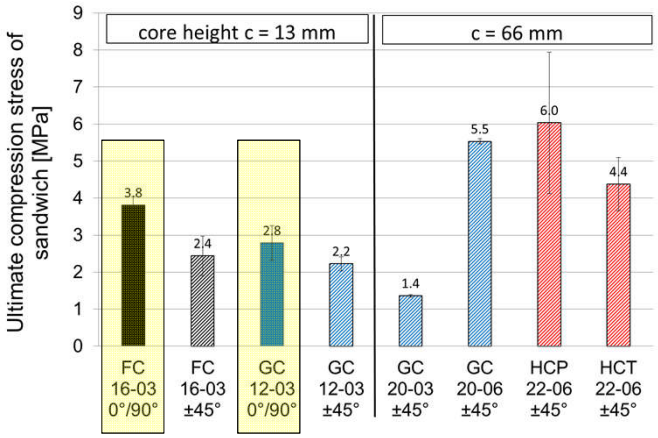
Modulus



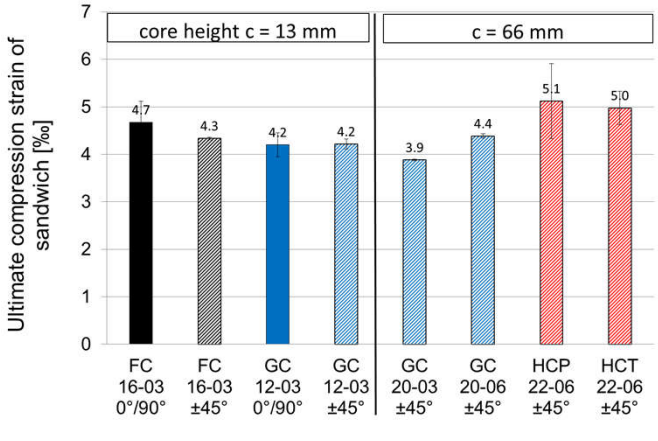
- Fibre orientation of 0° / 90° in core web leads to higher compression strength (12 - 30 %) and modulus (FC: 50%), compared to ± 45° webs
- Grid and honeycomb type cores ((t_c = 0.6) offer highest strength (F_{max} = 56 kN) and modulus
- Lowest properties for thin walled, high GC (t_c = 0.3; c = 68 mm), due to buckling at low loads

Compression Properties

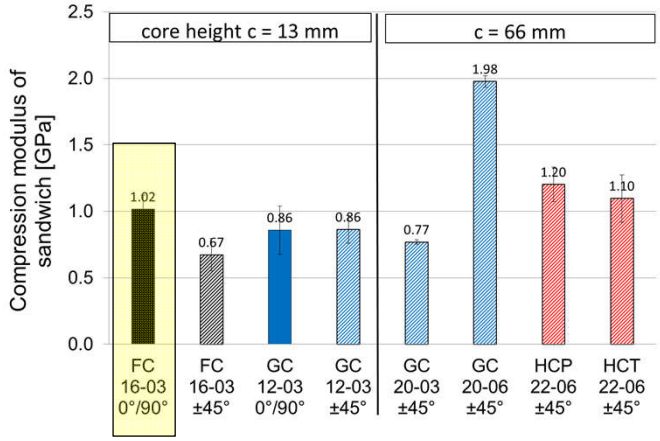
Strength



Strain



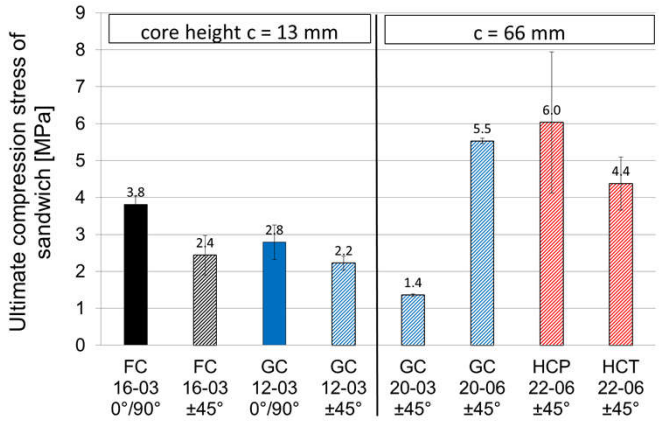
Modulus

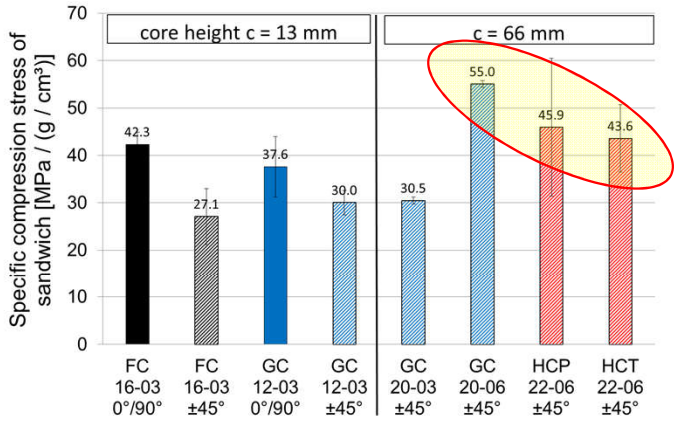


- Fibre orientation of 0° / 90° in core web leads to higher compression strength (12 - 30 %) and modulus (FC: 50%), compared to ± 45° webs
- Grid and honeycomb type cores ((t_c = 0.6) offer highest strength (F_{max} = 56 kN) and modulus
- Lowest properties for thin walled, high GC (t_c = 0.3; c = 68 mm), due to buckling at low loads

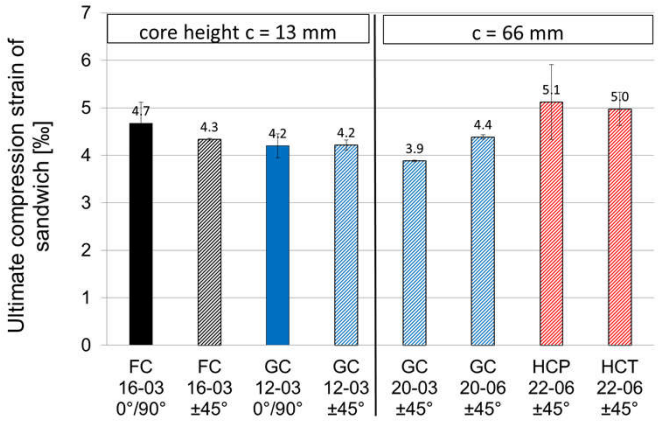
Specific Compression Properties

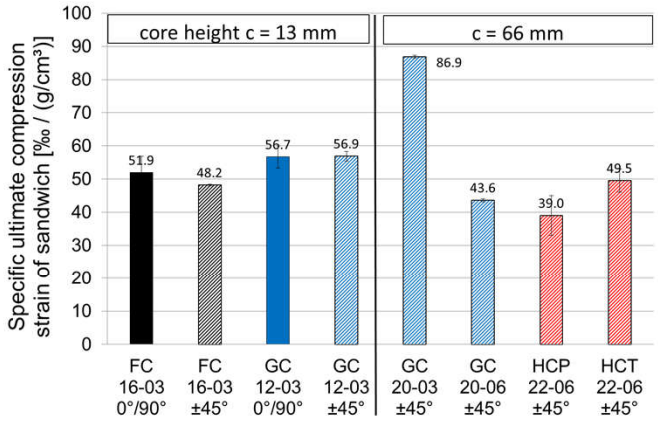
Strength



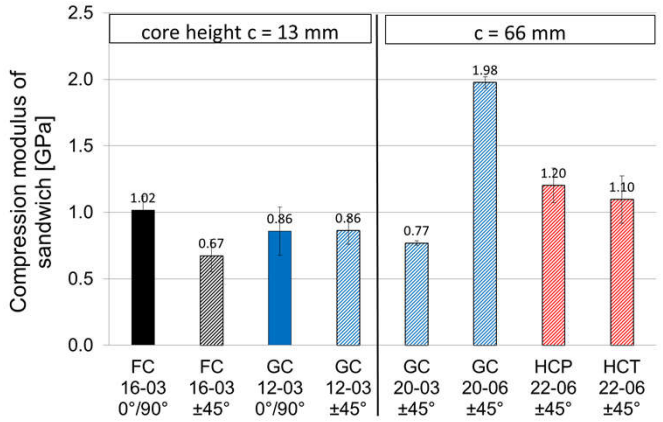


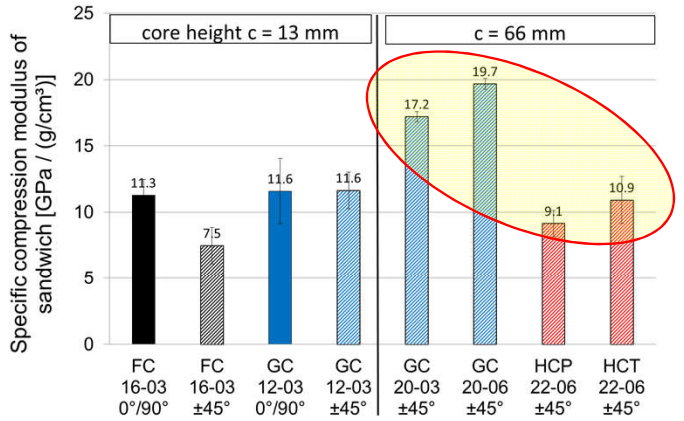
Strain



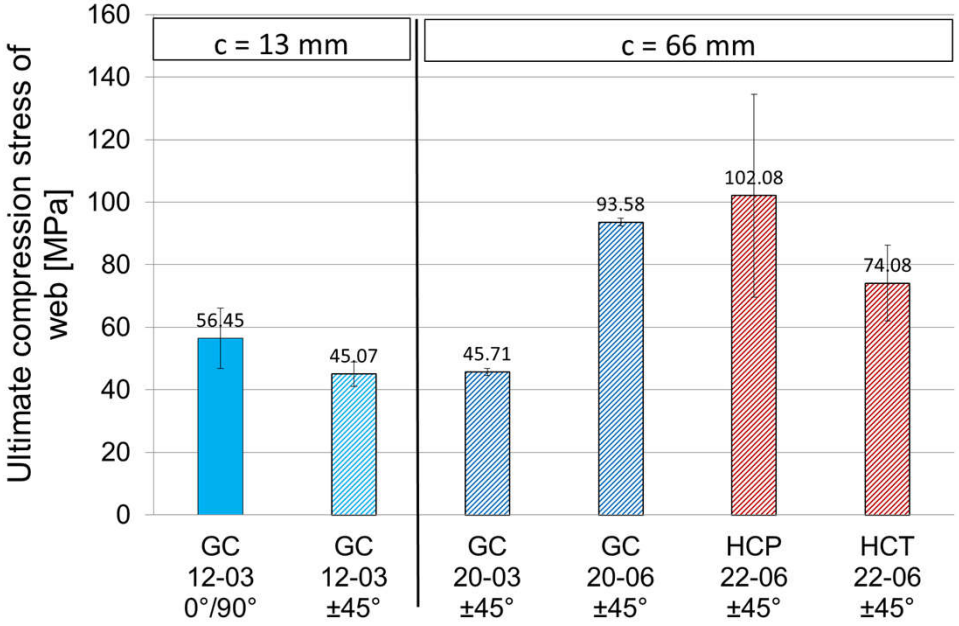


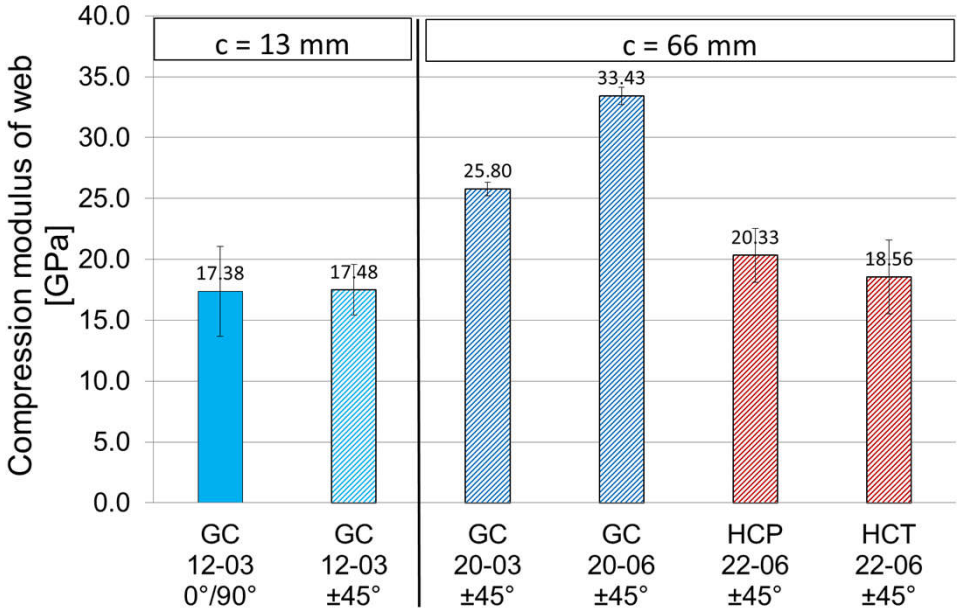
Modulus





Core Web Properties



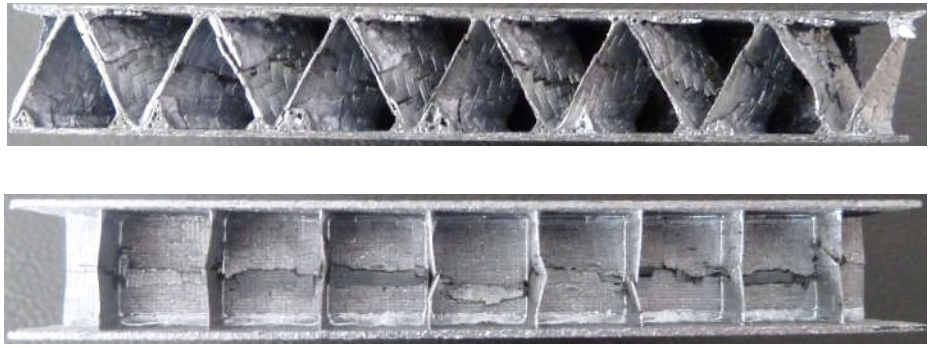


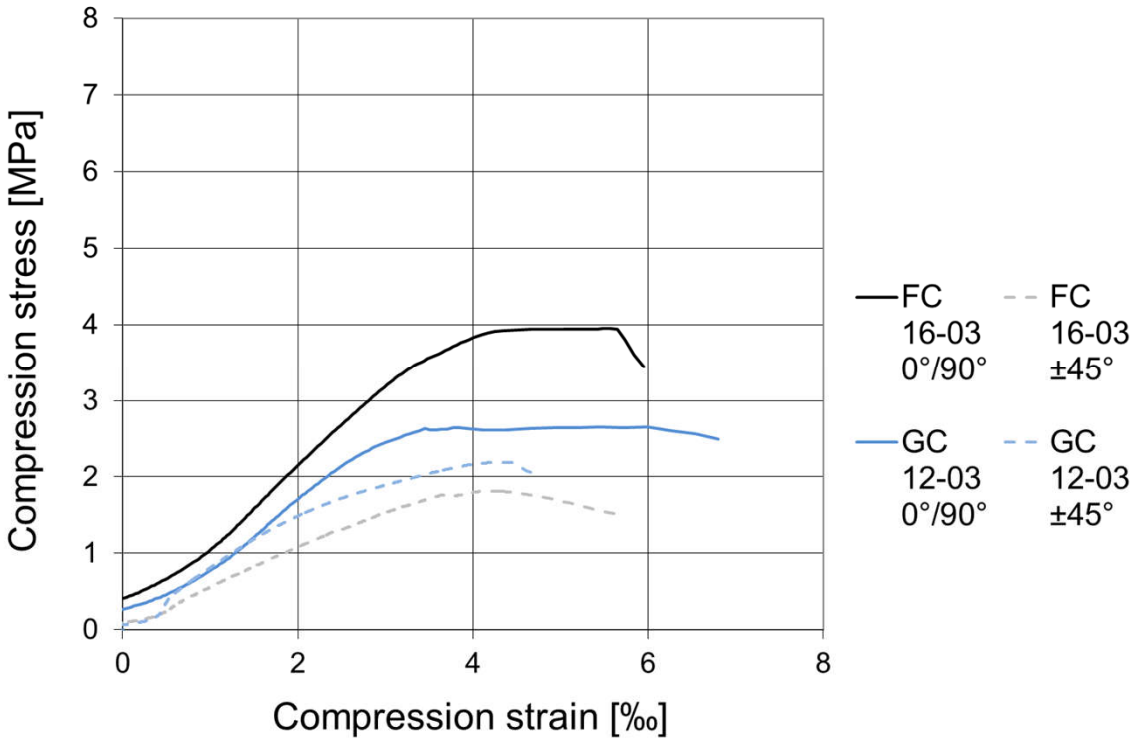
Compression stress (45 -102 MPa) and modulus (17 – 33 GPa) below C/C-SiC properties due to buckling

(Shi, Y., 2019: $\sigma_{c,\ 0°/90°}$ = 322 MPa; Hofmann, S, 2013: $E_{c,\ 0°/90°}$ = 56 GPa)

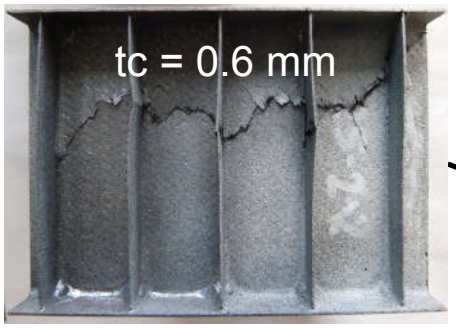
ReStress / Strain Behaviour and Failure Mode (c = 13 mm)

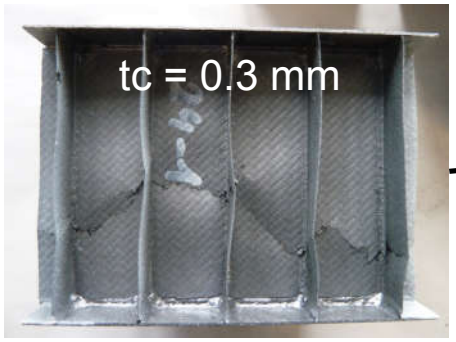
- Nonlinear stress strain behaviour
- Failure in buckling mode

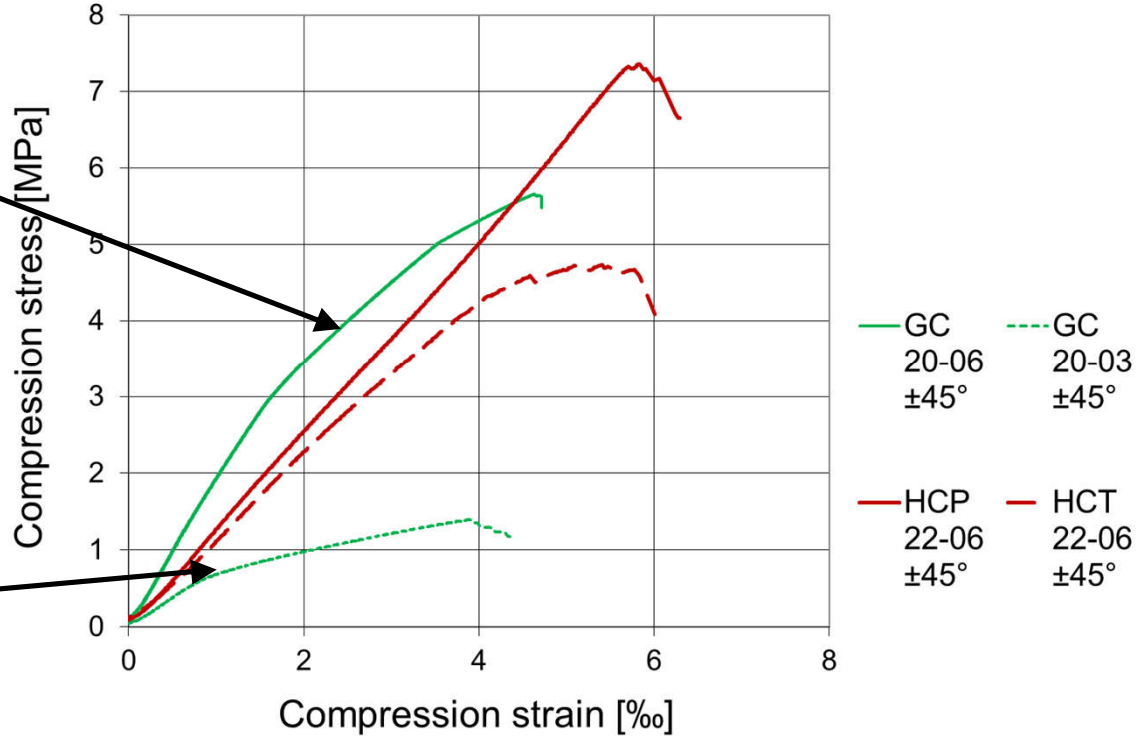




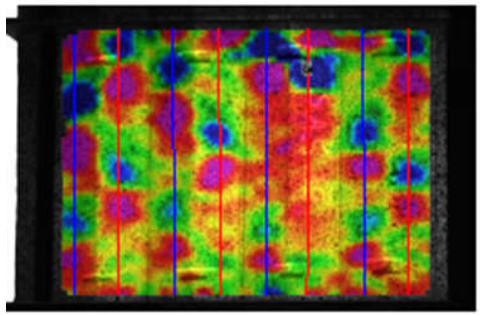
Results – Compression (c = 66 mm, GC)

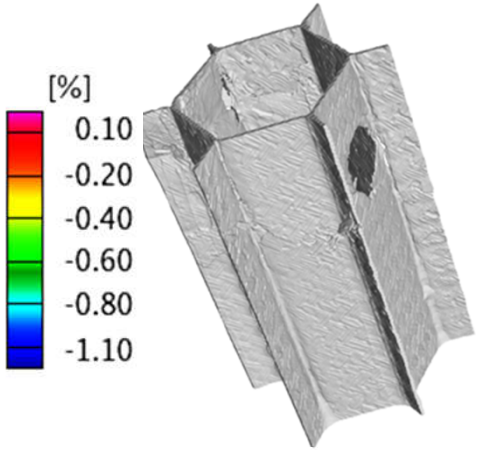


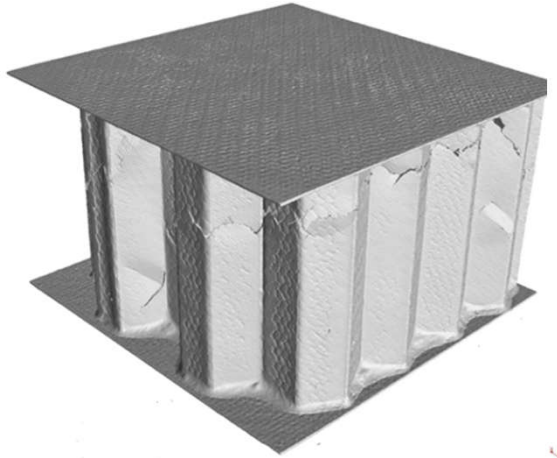


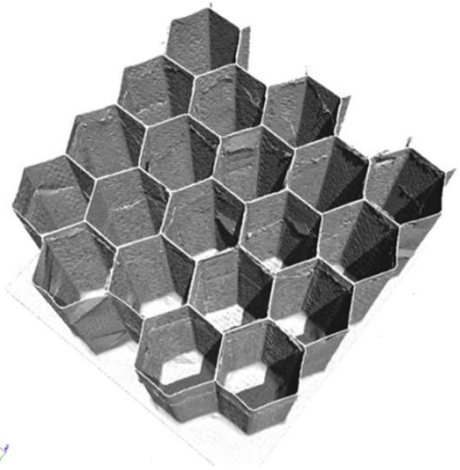


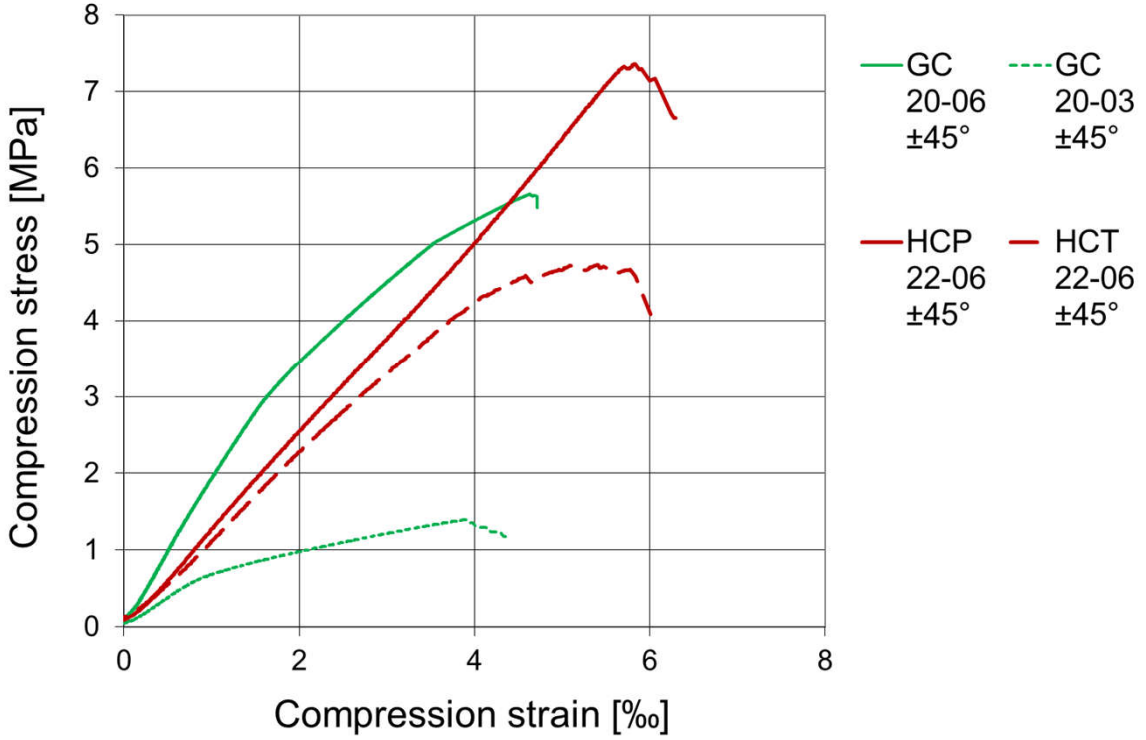
Results – Compression (c = 66 mm; HC)





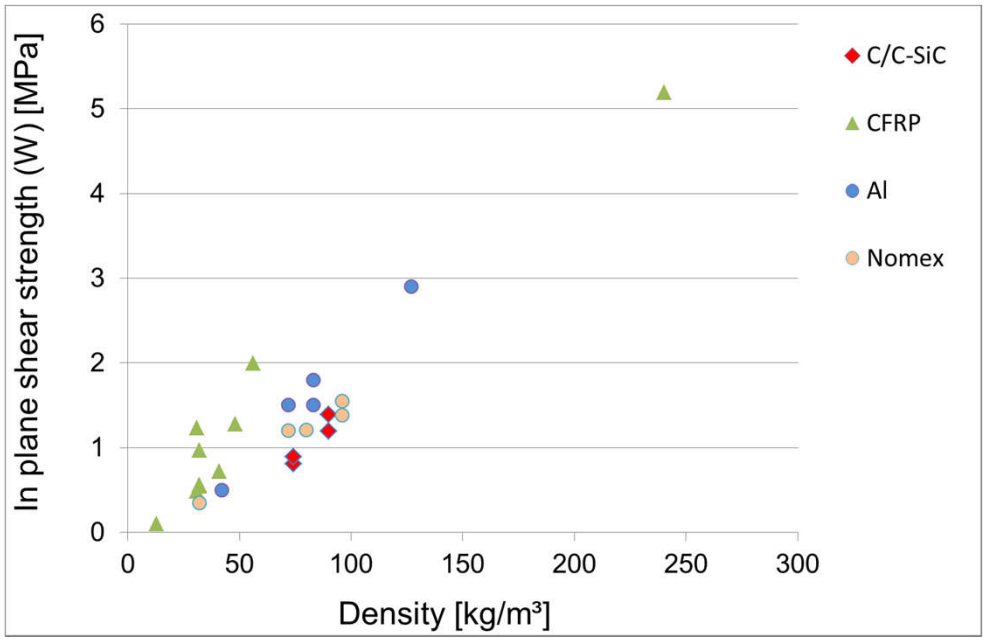




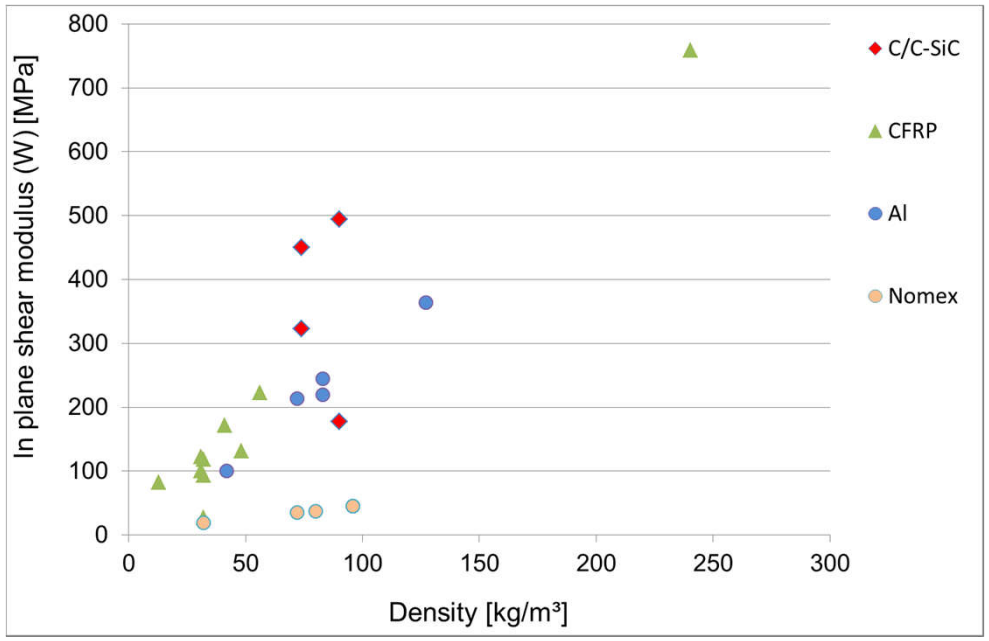


Comparison of Core Materials (Shear in W)

Strength



Modulus



Source:

C/C: Ultracor Inc., Stockton, USA

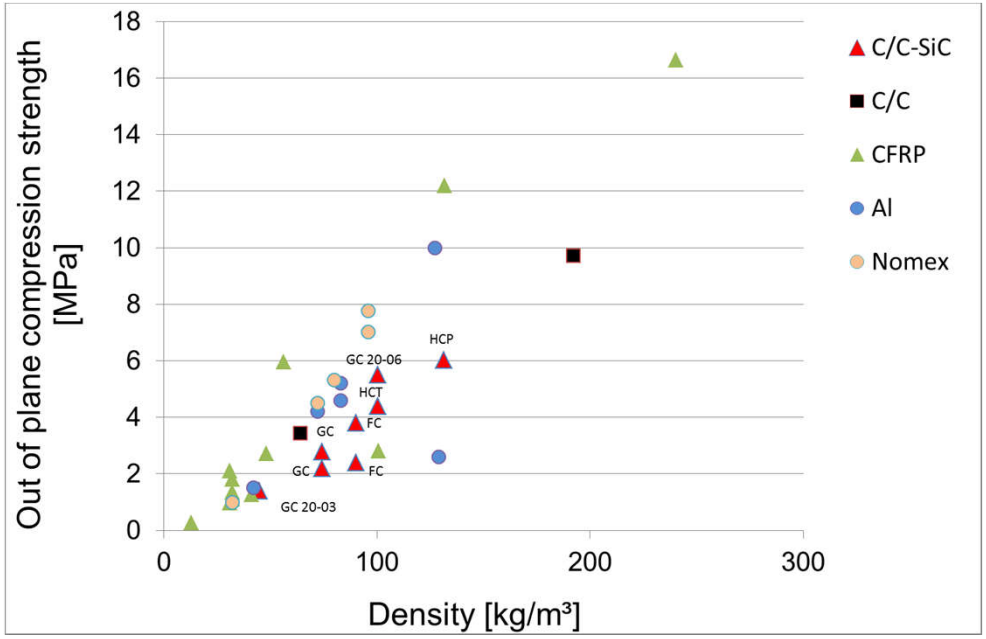
CFRP: Invent GmbH, Braunschweig, Germany;
Ultracor Inc., Stockton, USA

Al: Hexcel Corporation, Stamford, CT, USA

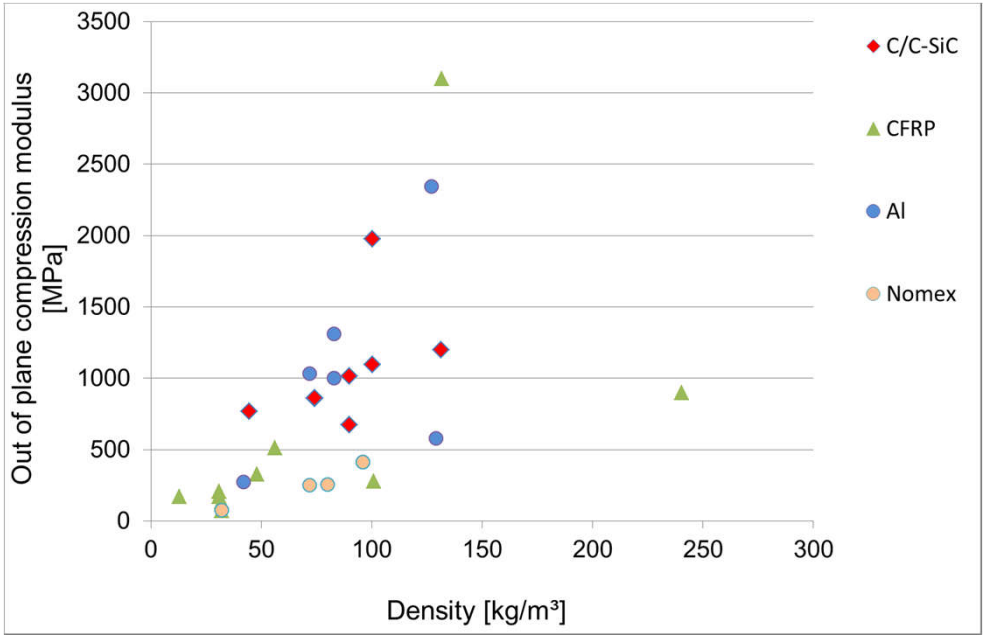
Nomex: Hexcel (Aramid fibre paper + phenolic coating)

Comparison of Core Materials (Compression)

Strength



Modulus



Source:

C/C: Ultracor Inc., Stockton, USA

CFRP: Invent GmbH, Braunschweig, Germany;
Ultracor Inc., Stockton, USA

Al: Hexcel Corporation, Stamford, CT, USA

Nomex: Hexcel (Aramid fibre paper + phenolic coating)

Summary

- C/C-SiC Sandwich structures were manufactured via LSI, using 4 different core types and core heights
- Mechanical properties mainly influenced by fiber orientation in the core and by core wall thickness
  - 0° / 90° → High compression strength and modulus
    → High shear strain
  - ± 45° → High shear strength and modulus
  - t_c = 0.6 mm → High specific compression strength and modulus
- Specific compression strength and modulus of grid core higher compared to honeycomb core (t_C = 0.6). Linear elastic stress / strain behavior of high core (c = 66 mm; t_C = 0.6 mm). In a wide rage.
- Fold cores offer higher shear strength and modulus compared to grid core.
- Core strength and modulus lower than material properties due to buckling of thin walls (0.3 / 0.6 mm)→ adapt core design (cell width, height) for applications

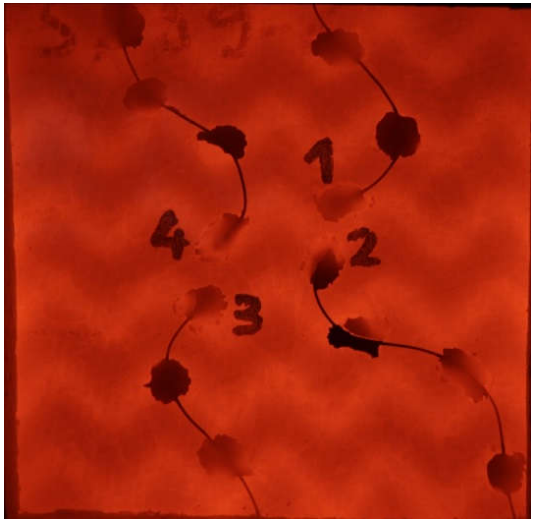
Acknowledgements

- Support by ESA project NPI 318-2013; Contract-No. 4000111641/14/NL/PA
- ESTEC team from Materials Technology Section for mechanical testing
- DLR team and students for sample manufacture / processing and non destructive testing, especially Raouf Jemmali, Lion Friedrich, Nicole Gottschalk

References

- Yuan Shi, Yanlei Xiu, Dietmar Koch, Investigation of Statistical Distribution of C/C-SiC Composite's Mechanical Properties, Key Engineering Materials, 2019
- S. Hofmann, "Effect of interlaminar defects on the mechanical behaviour of carbon fibre reinforced silicon carbide," Dissertation, Institute of Aircraft Design, University Stuttgart, 2013

Presentations in the Afternoon Session



- **Thomas Reimer**, CMC Sandwich Development and Testing for High-Temperature Space Application

- **Yuan Shi**, Characterization and modeling of bending properties of continuous fiber reinforced C/C-SiC sandwich structure