C/C-SIC SANDWICH STRUCTURE FOR OPTICAL BENCH

CMCs in Europe

Workshop 2025

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Outline

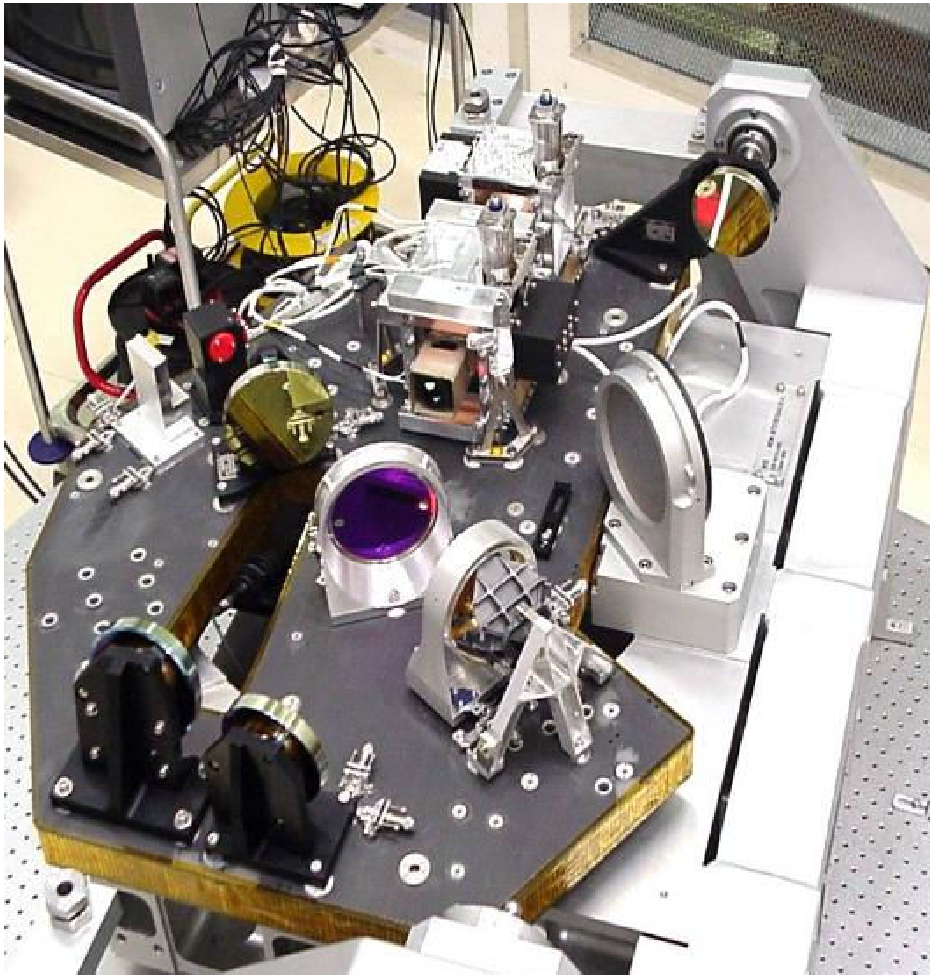
- C/C-SiC for optical benches
- Sandwich manufacture
- Sandwich copupon characterization
- Demonstrator manufacture
- Demonstrator testing
- Conclusion

What is an Optical Bench (OB) ?

- Platform for laser systems and optical instruments
- Stable alignment of optical elements
  - Highly stiff for minimal deflection
  - Temperature changes and moisture
  - Vibrations (launch, operation)
  - long term stable in space environment
- Typical materials: SiC, Zerodur, CFRP sandwich, C/C sandwich (GOCE)

New approach:

Ultrastable OB made of CMC sandwich structures (**C**eramic **M**atrix **C**omposites)



Optical Bench for IASI made of CFRP sandwich (Thales Alenia Space)

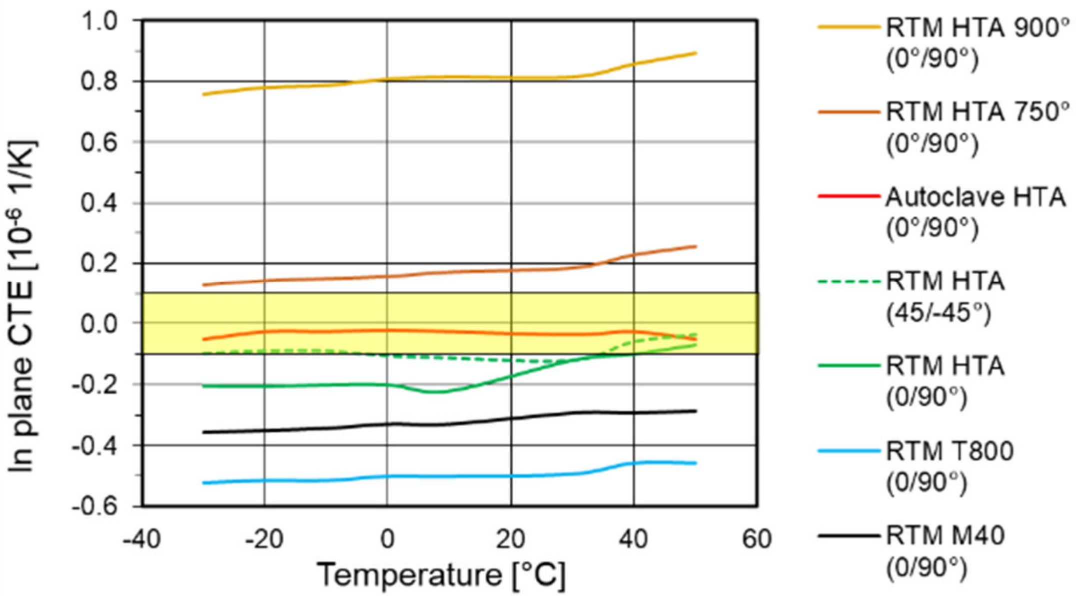
C/C-SiC Sandwich Structures for Optical Benches

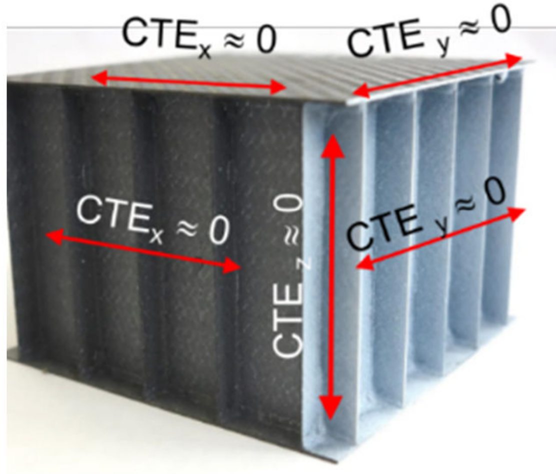
ThalesAlenia Space — a Thales / Leonardo company

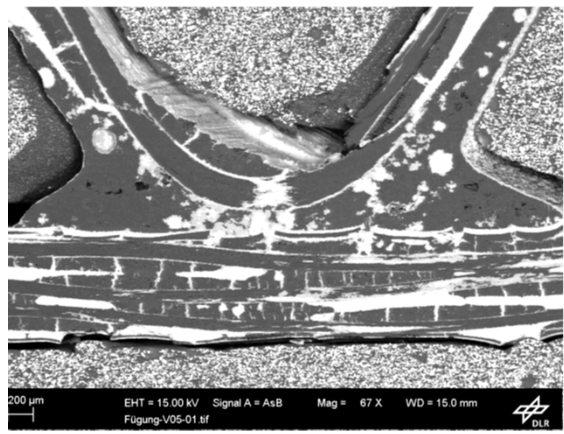
DLR

- High specific stiffness + sandwich design → Lightweight and highly stiff structures
- Skin and core structures made of C/C-SiC → Very low thermal expansion in all directions
- Ceramic joining of skins and core (no polymers) → long term stable / no outgassing in space

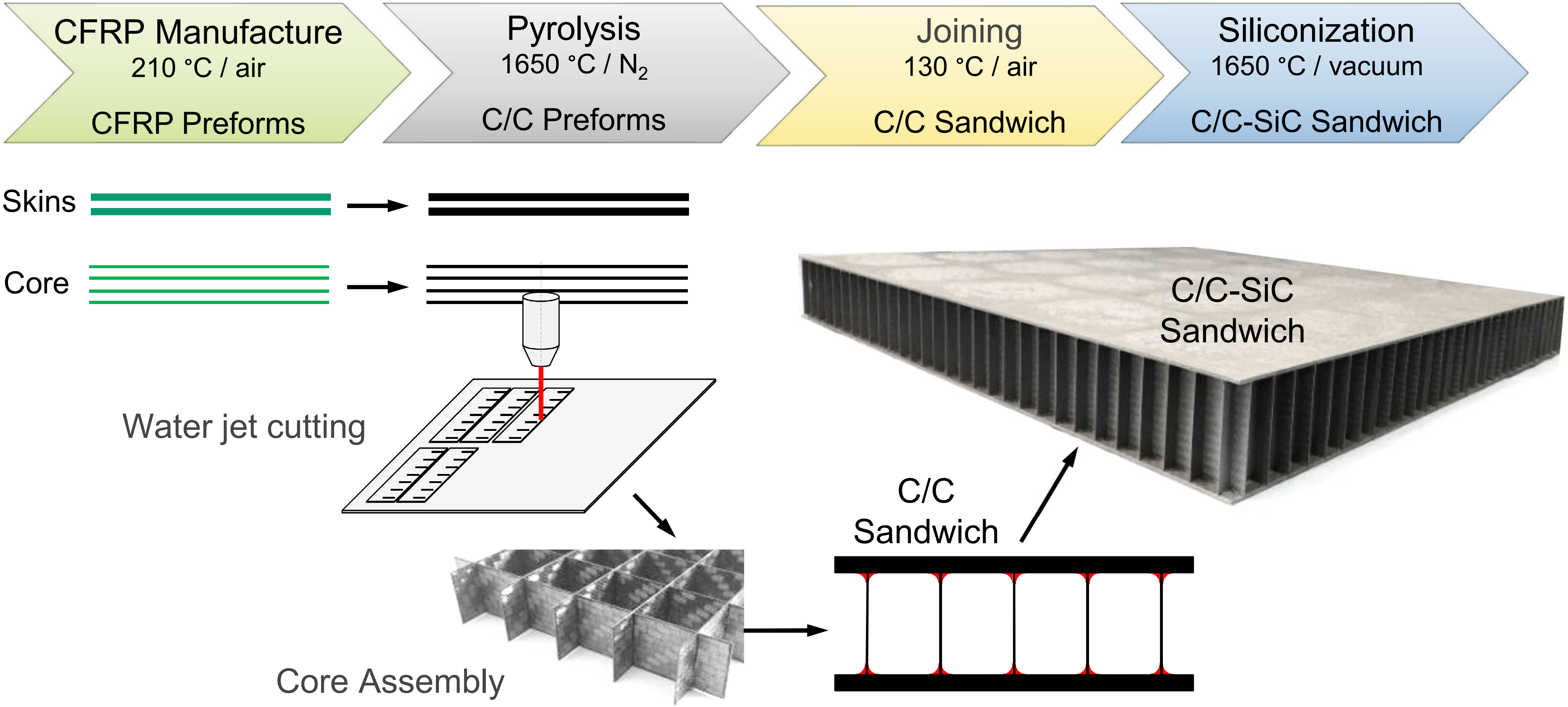
→ **Ultrastable optical benches for space applications**



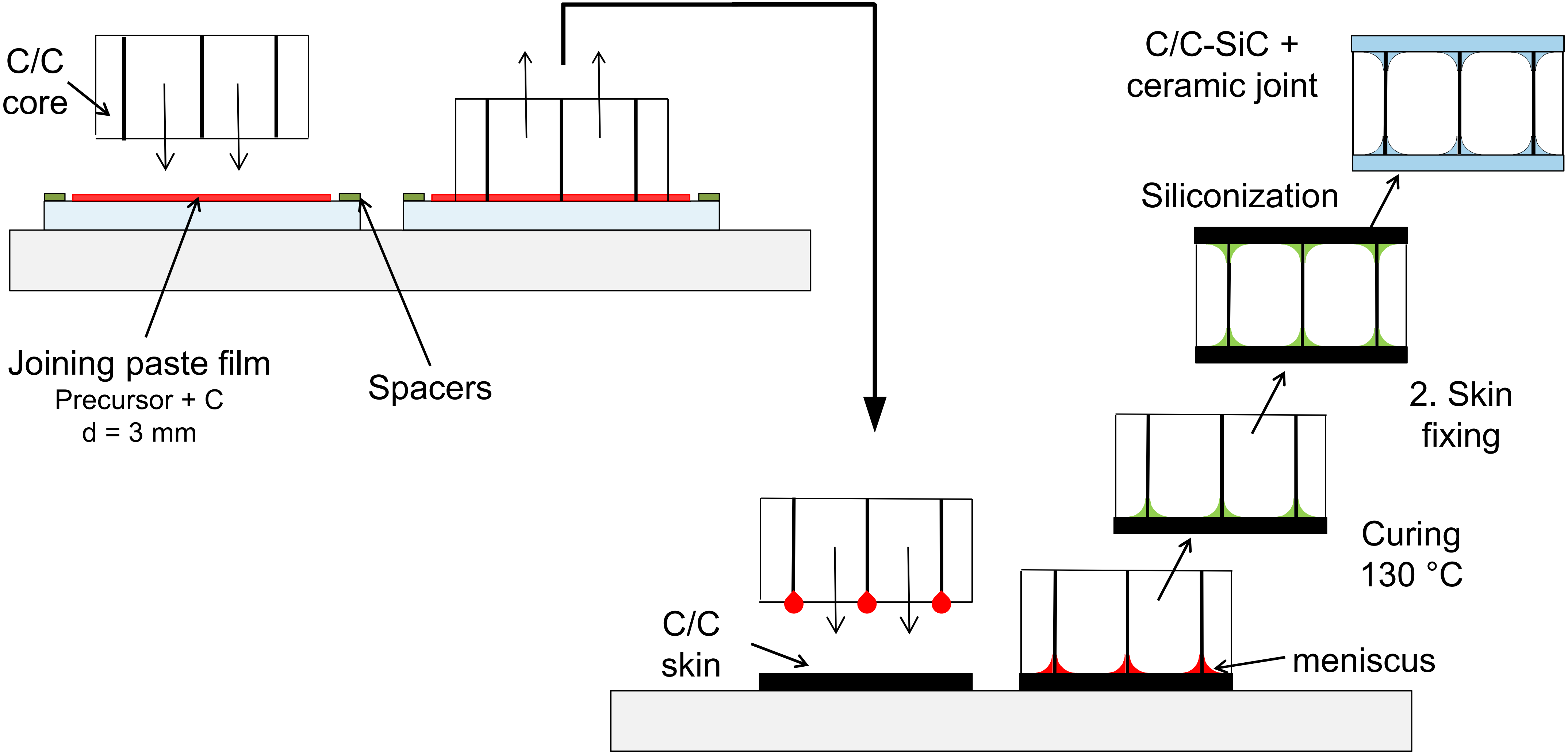




Manufacture of C/C-SiC Sandwich via LSI



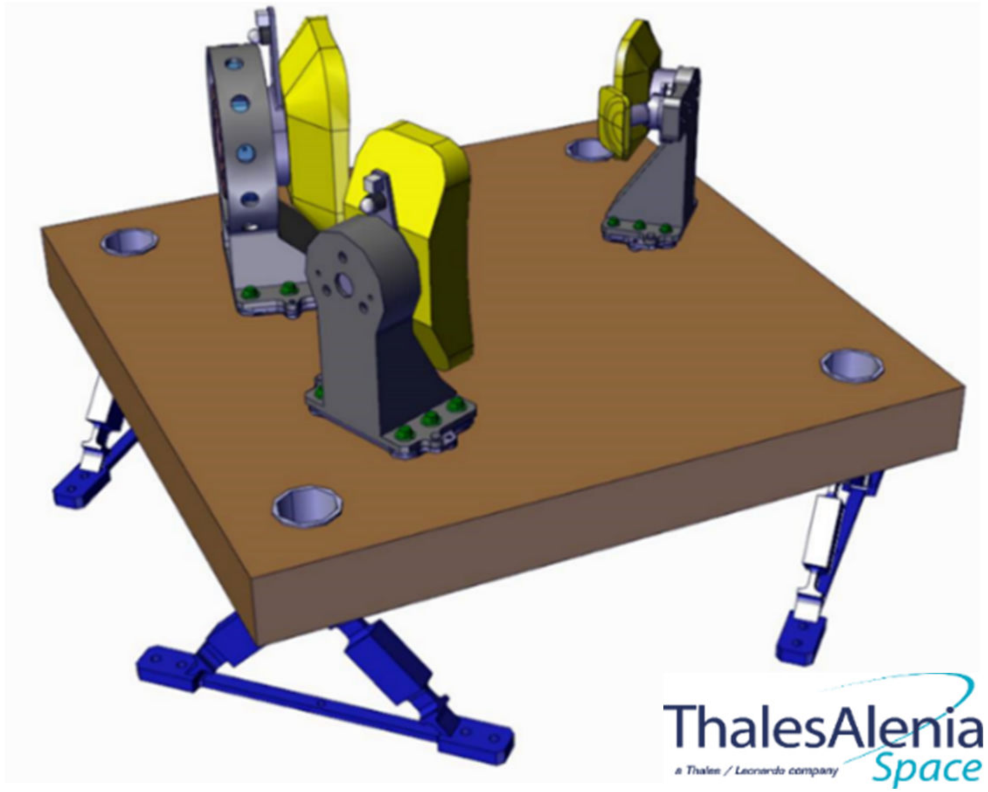
Joining of the Core to the Skins



ESA TDE project: Development of a C/C-SiC Optical Bench Demonstrator

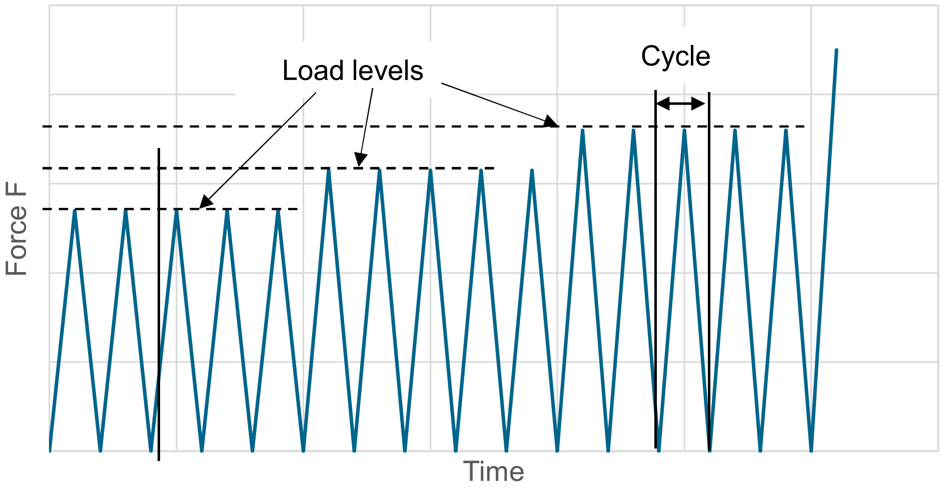
Requirements

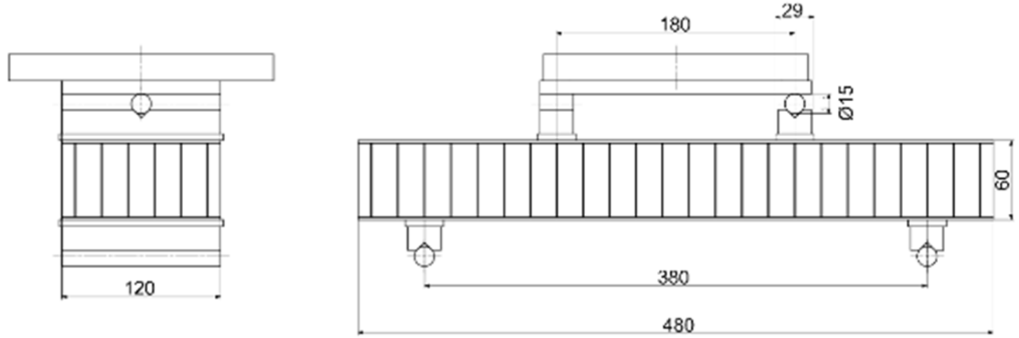
- Sandwich demonstrator ≥ 600 x 600 mm²
- Interface concepts
- CTE in all directions < 5 x 10 $^{-6}$ K^{-1}
- Integrity during thermal cycling between -170 °C and 100 °C
- Integrity after sine and random vibration under 20g
- Natural frequency > 140 Hz

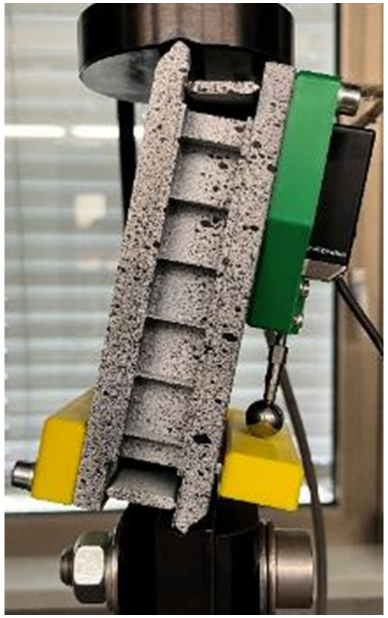


Characterization Program

- Sandwich samples
  - 4-pt. bending (480 x 120 x 60 mm³)
  - In plane shear (120 x 80 x 24 mm³)
  - Out of plane tension (50 x 50 x 16)
- Interface samples
- Develop and validate a simulation model
- Quasistatic cyclic testing → mechanical stability

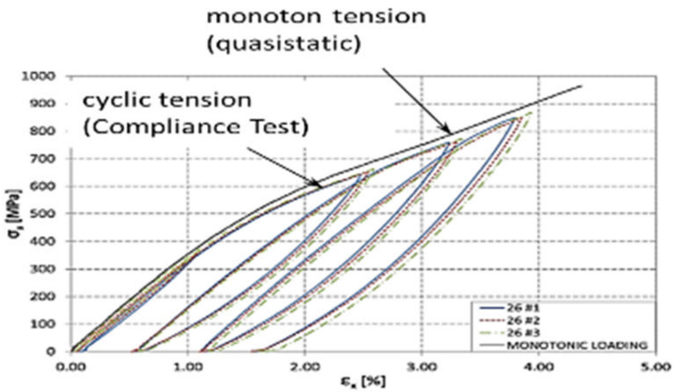






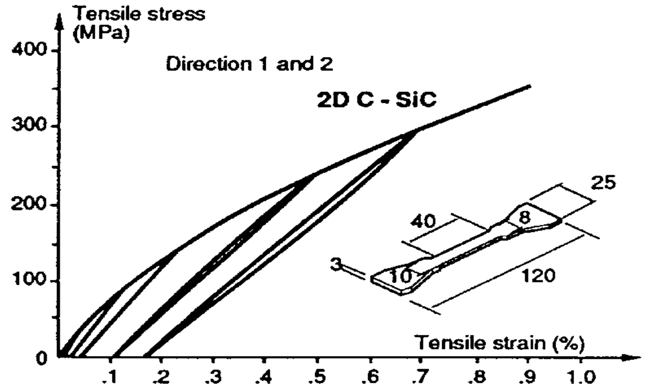
Cyclic Testing of Composites

CFRP



J. D. Fuller, M.R. Wilson, Ductility and pseudo-ductility of thin ply angle-ply CFRP laminates under quasi-static cyclic loading, Composites: Part A 107, pp 31 – 38, 2018]

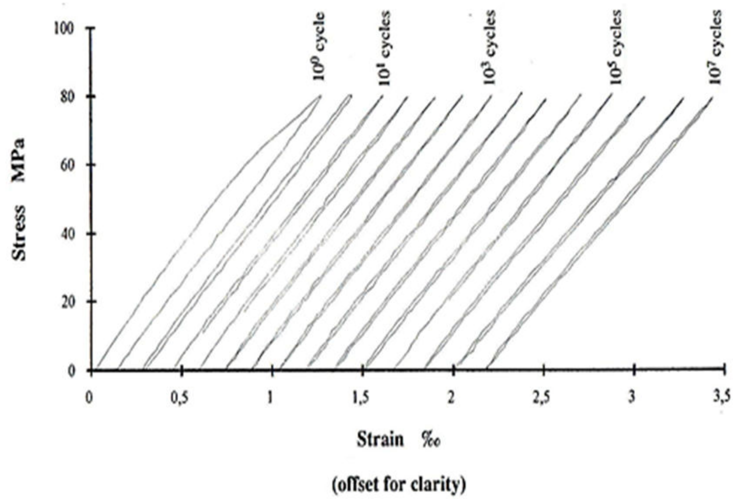
C/SiC (CVI)



D. Desnoyer, A. Lacombe, J.M. Rouges, *Large Thin Composite Structural Parts*, Proceedings of International Conference Spacecraft Structures and Mechanical Testing, Nordwijk, The Netherlands, 1991]

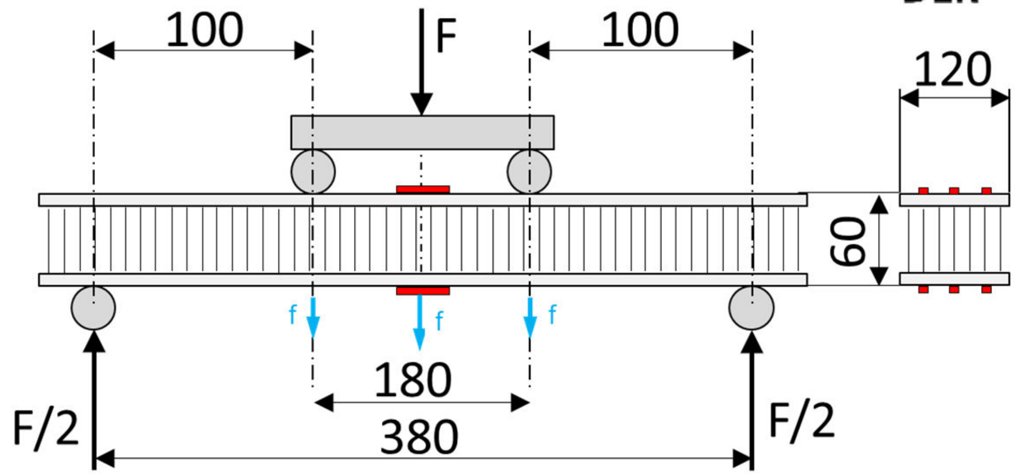
C/C-SiC (LSI)

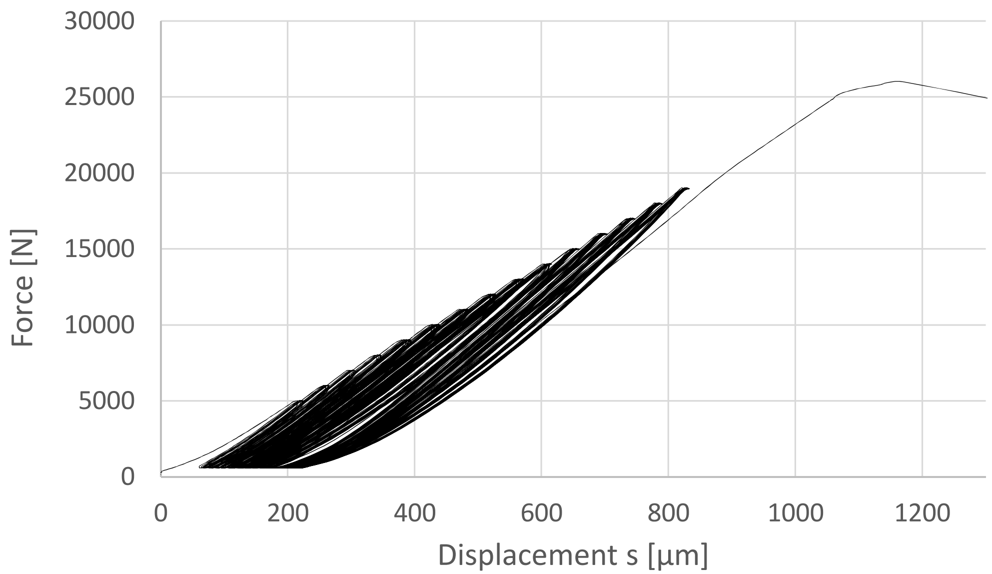
[Kochendörfer, 2000]

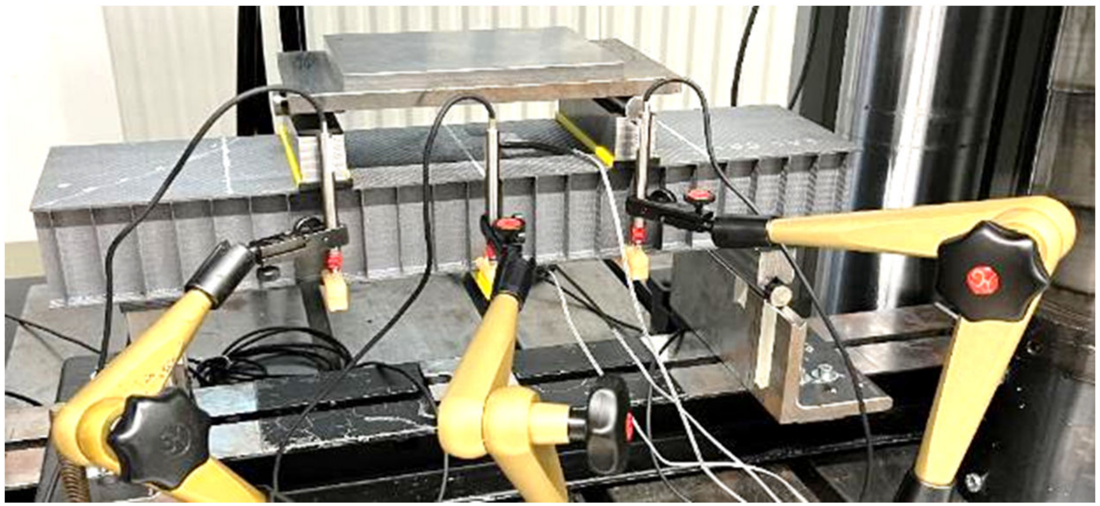


4-Pt.- Bending Test of Sandwich Samples

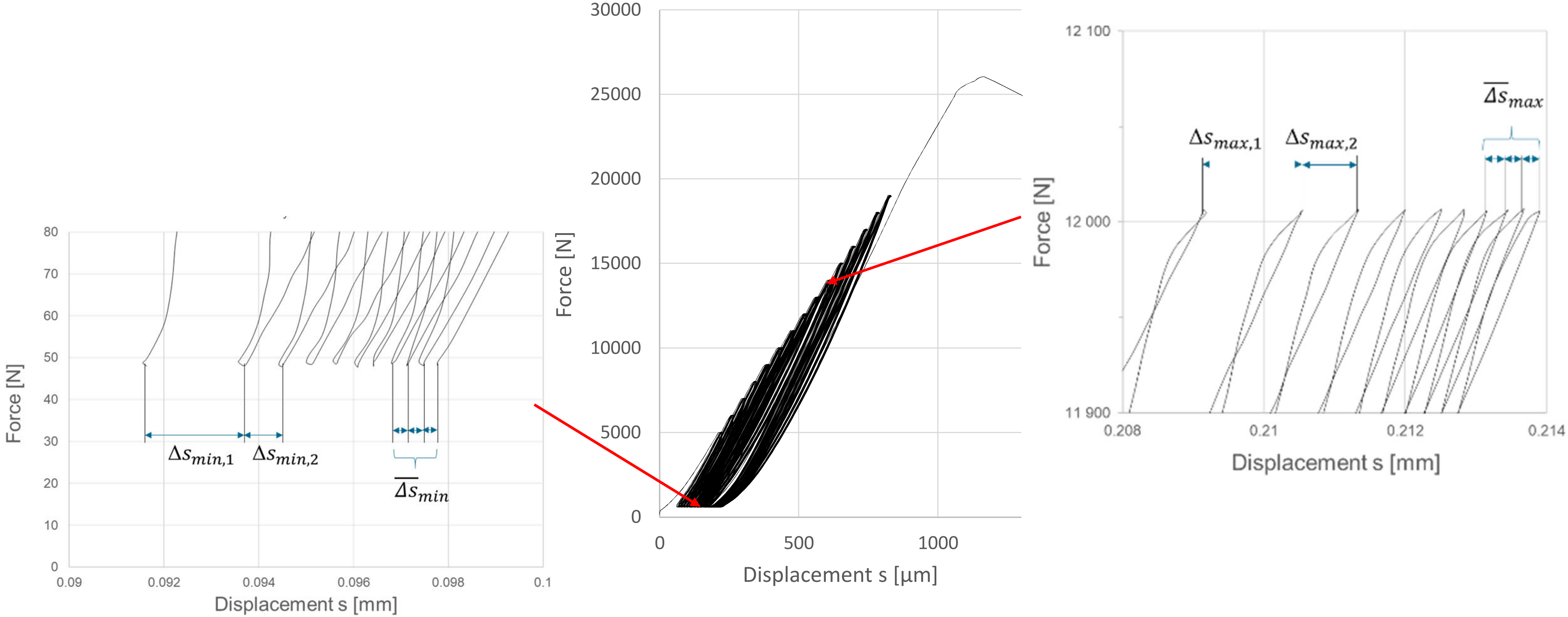
- 4-Pt. Bending according to DIN 53239
- Modelling and FEM simulation for sample geometry definition (480 x 120 x 60 mm³)
- Accurate measurement of displacements (LVDT)
- Quasistatic cyclic testing → mechanical stability







Cyclic Testing of C/C-SiC Sandwich

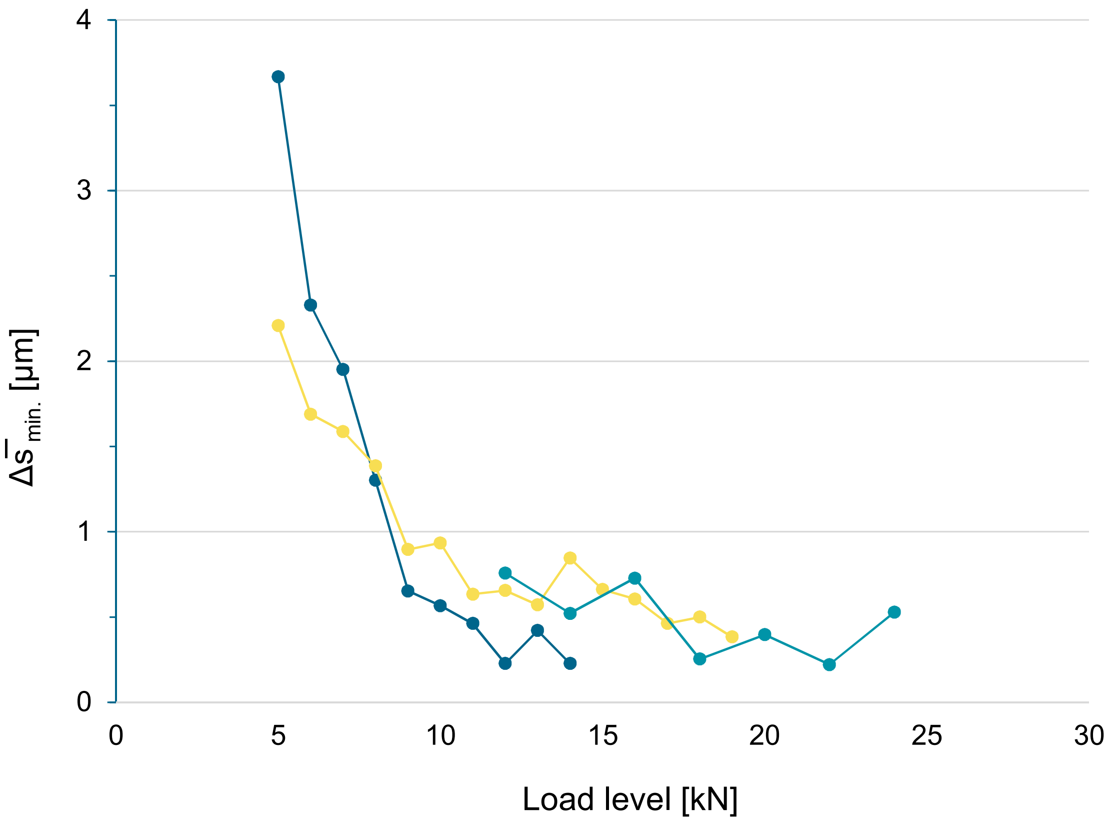


Stable structure <=> s = constant <=> Δ s = 0 ; $\overline{\Delta s} = 0$

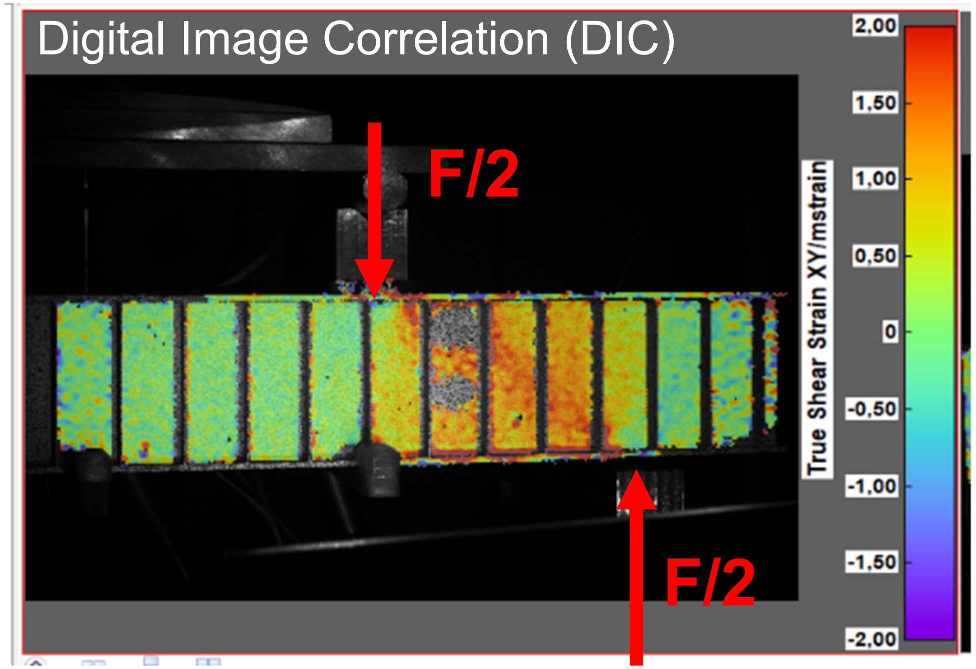
Stability of C/C-SiC Sandwich in 4-Pt. Bending

- Lower loads → residual displacements increase slightly (settling effect, due to complex test set-up)
- load levels > 10 kN, the residual displacements are minimal (< 1 µm = sensor accuracy)

→ C/C-SiC sandwich is stable after preloading



Failure Mode



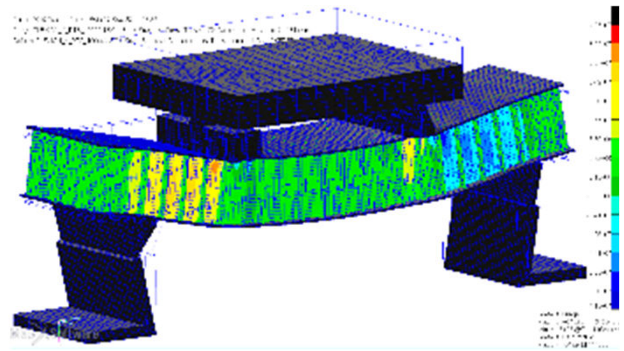
- F_u = 22.3 ± 3.1 kN ; σ_u = 82.8 ± 4.1 MPa
- Shear failure of core web in critical load span, followed by local core/skin debonding
- 480 x 120 x 60 m^3

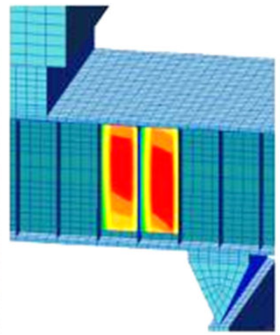
Results

			Theo- retical	Test		FEM
				Mean	Deviation	
Failure Load	F_u	[kN]	20.0	22.3	3.1	17.5
Displacement at ultimate load	f_u	[µm]	1 185	940	141	485
Ultimate shear stress in webs	$\tau_{web,u.}$	[MPa]	71.7	82.8	11.4	71.7
Ultimate tension stress in skin	$\sigma_{skin,\,u}$	[MPa]	74.2	68.7	12.5	51.0

Allowable shear stress $\tau_{web,\ allowable}$ = 71.7 Mpa

Allowable tensile stress $\sigma_{skin,\ allowable}$ = 86 MPa





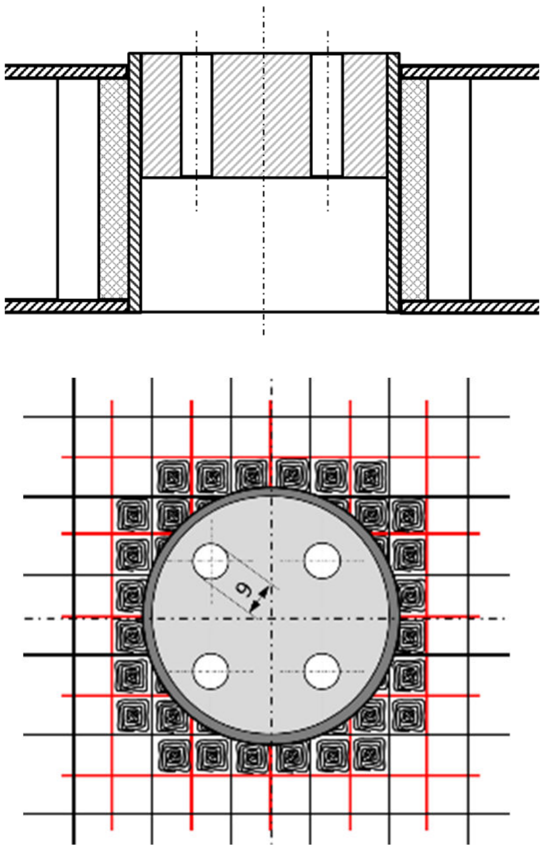
- FEM (NASTRAN solver + PATRAN) predicts shear failure, but lower failure load and skin stresses
- Lower displacement due to complex set-up, tilting, linear instead of non-linear calculation
- Maximum stresses in skins and core webs close to material strengths → well-balanced design

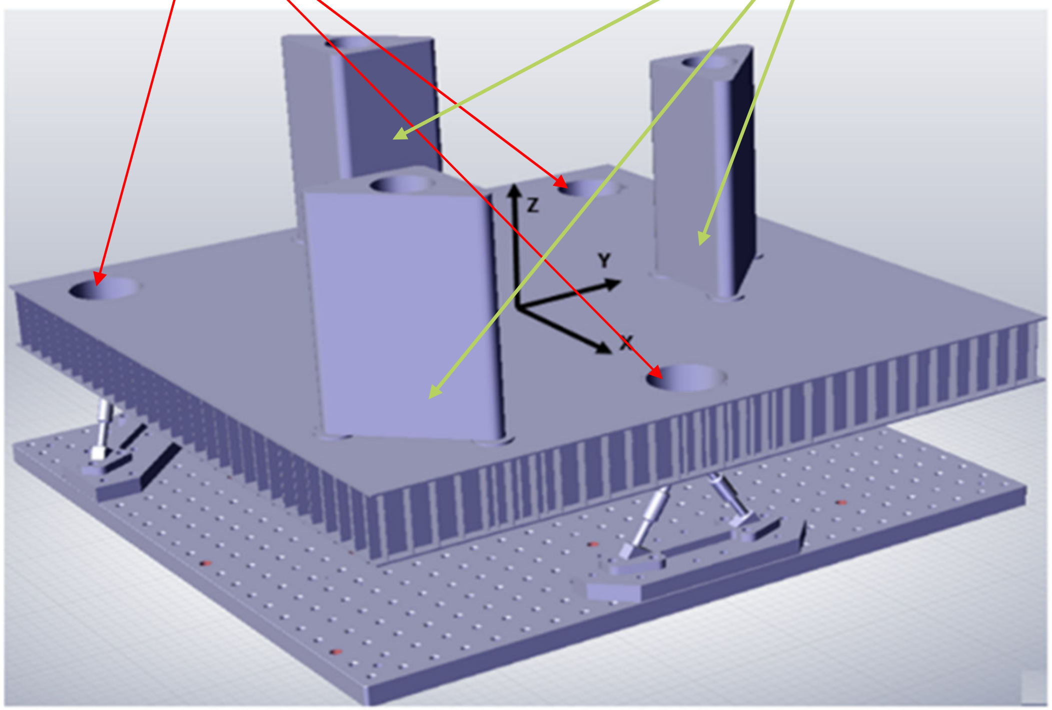
Characterization of C/C-SiC Interfaces

3 x Interface XL
OB ↔ satellite

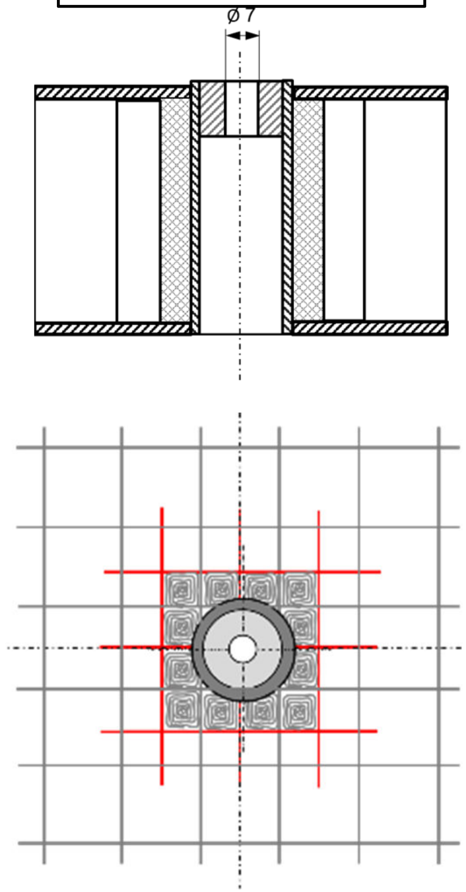
3 x 3 Interface XS
instrument ↔ OB

Interface XL





Interface XS



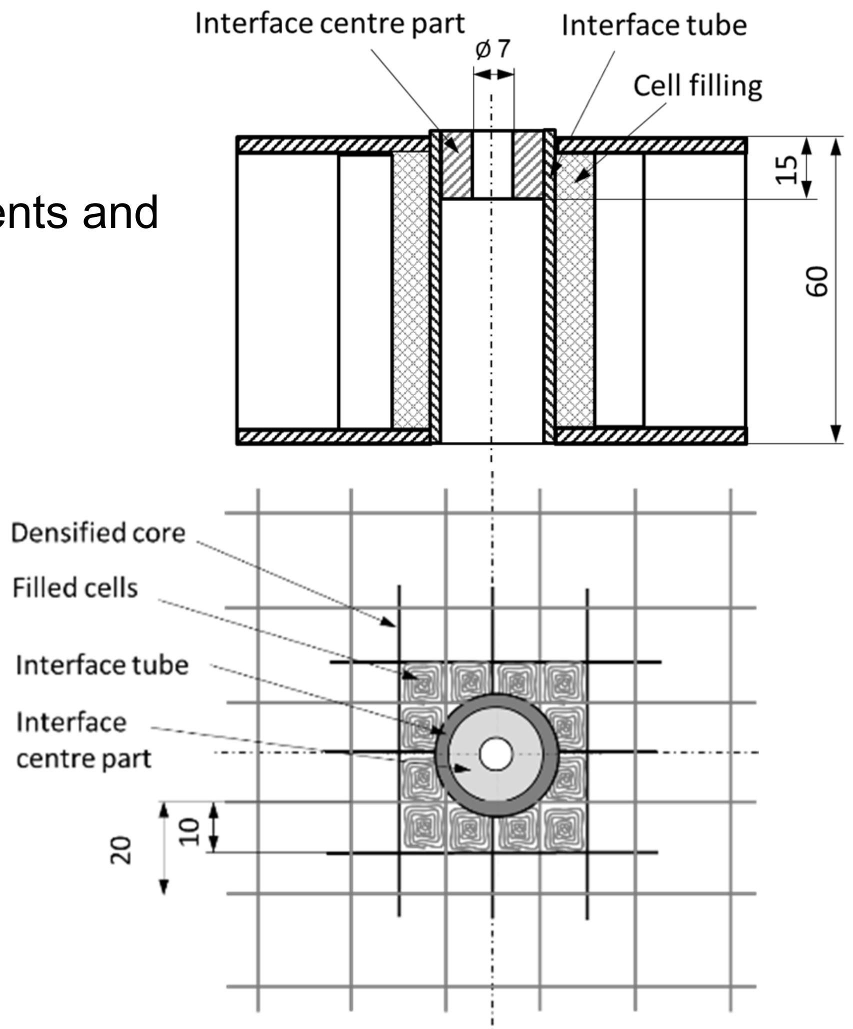
C/C-SiC Interface Concept

Aim

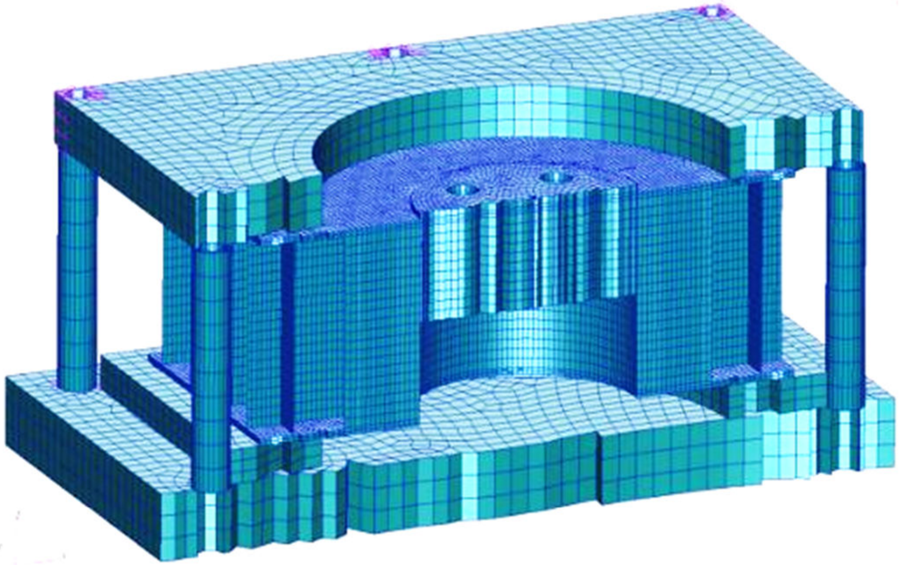
- Safe load transfer to core structure via shear stresses
- Minimized CTE mismatch between interface components and sandwich structure

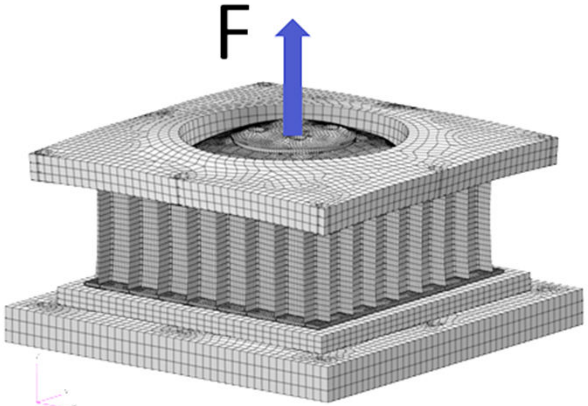
Approach

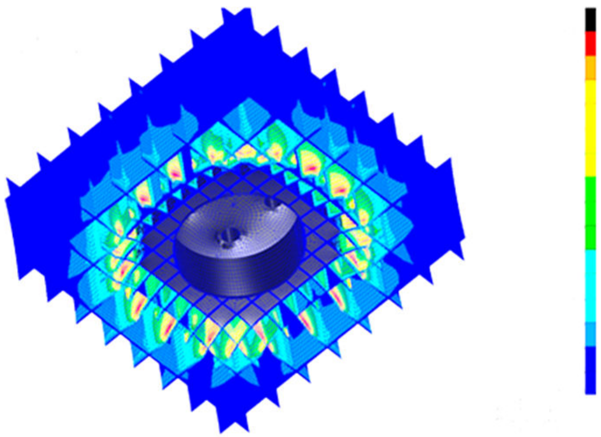
- All C/C-SiC design, no metallic inserts / polymers
- Interface concept based on
  - Densified core
  - Filling of core cells
  - Interface tube
  - Massive centre part with boring (wrapped, plate)
  - Ti screws and nuts



Simulation and Test

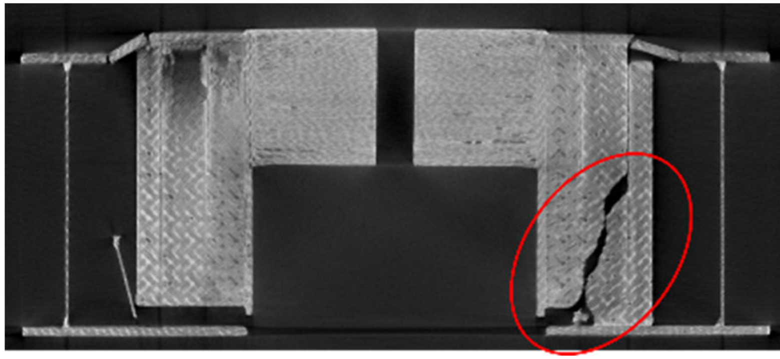


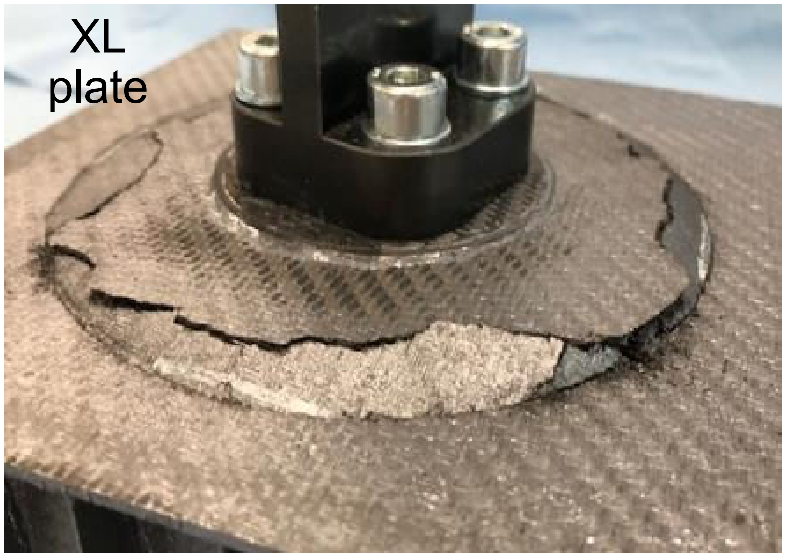




Test Results - Interface Samples

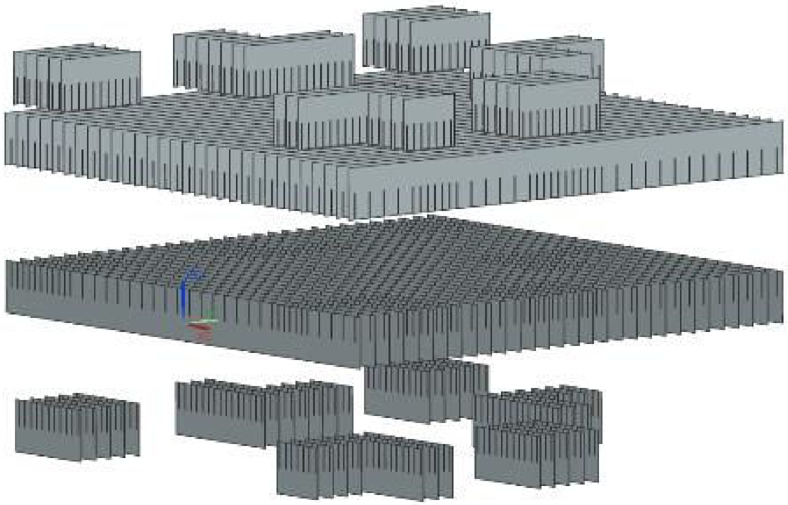
		XS wrapped	XS plate	XL wrapped	XL plate
Fibre orientation in centre part	[°]	∥ ± 45°	⊥ 0°/90°	∥ ± 45°	⊥ 0°/90°
Ultimate force	[kN]	18.0 ± 0.7	16.1 ± 2.0	> 24 test stopped	47.9
Safety factor (SF)	[-]	5.8	4.7	> 4.8	9.6

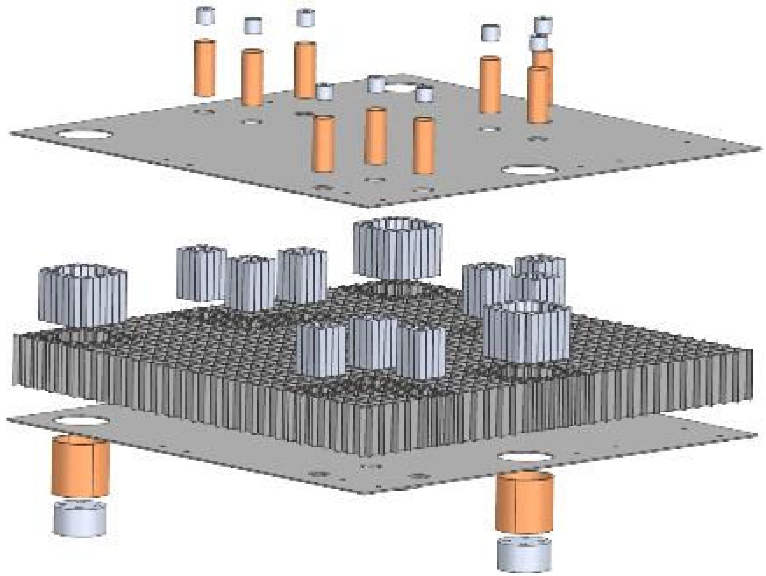


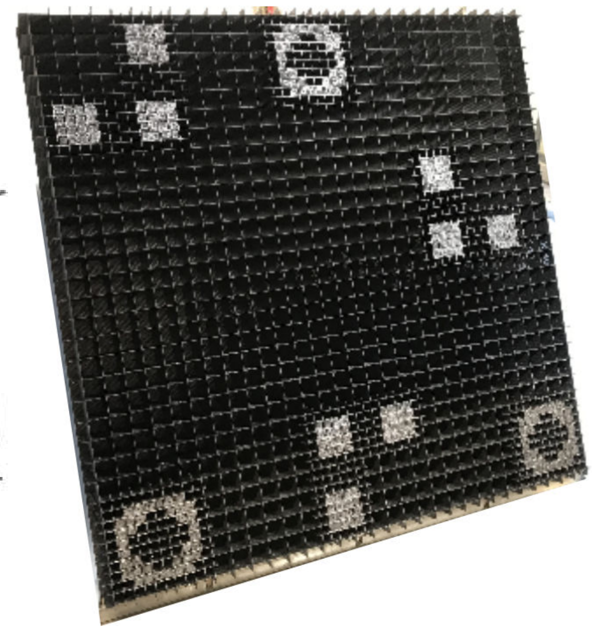


Demonstrator Manufacture

- Design: t_s = 2 mm; t_c = 0.6 mm; w = 20 / 10 mm
- Sandwich structure with integrated interfaces
- Core: 123 webs / 20 different geometries
- m = 7.5 kg (0.35 g/cm³) / 4.8 kg (0.22 g/cm³)







Thermal Testing (TAS)

- Thermal excursion (-170°C to 100 °C) ✓

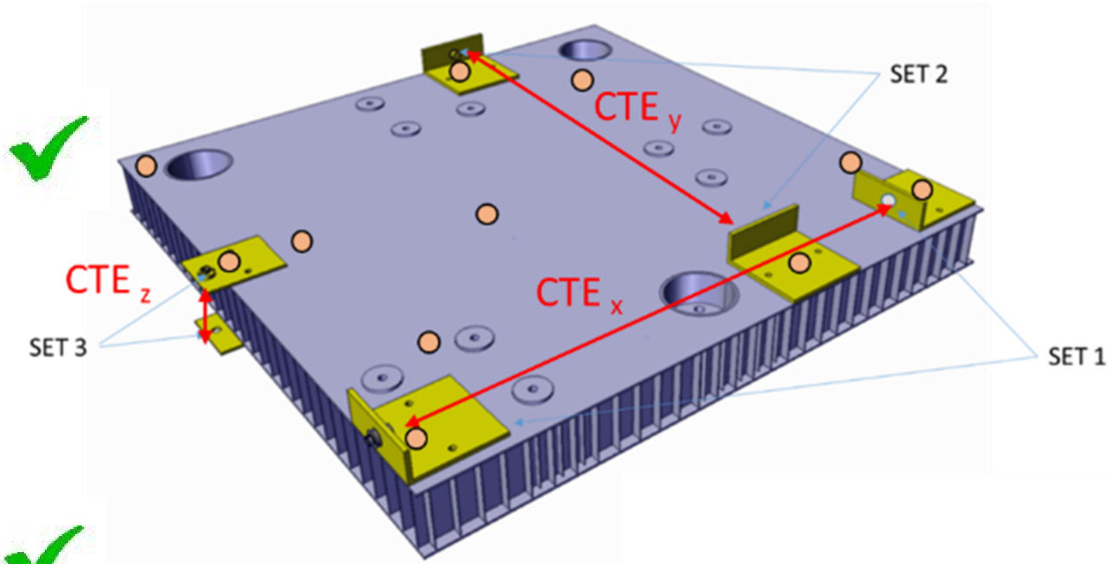
  Photogrammetric measurements

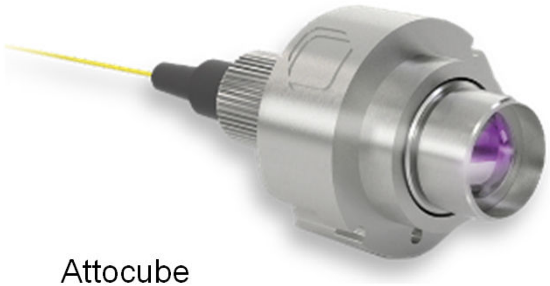
- CTE in x, y, z direction (0 °C to 40 °C)

  High precision interferometric measurements of distances

  → CTE $_{x/y}$ = -0.48 / -0.56 · 10^{-6} K^{-1} ✓

  → CTE $_z$ to be verified

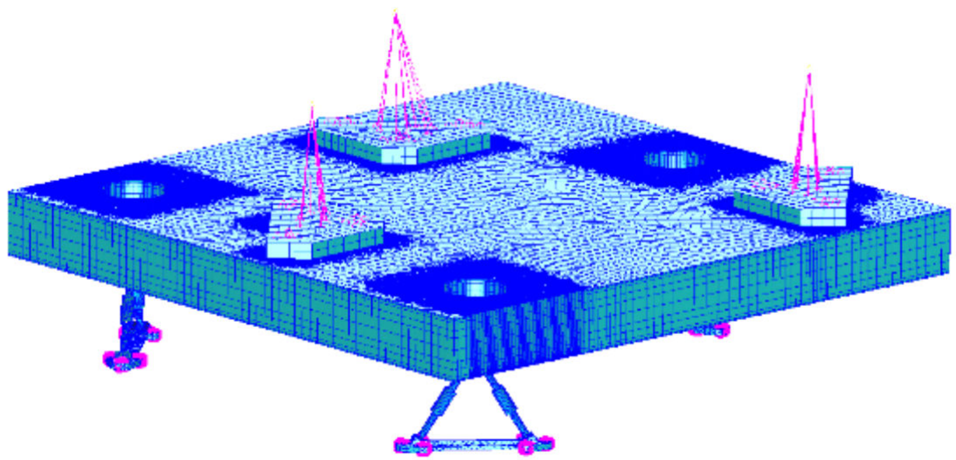




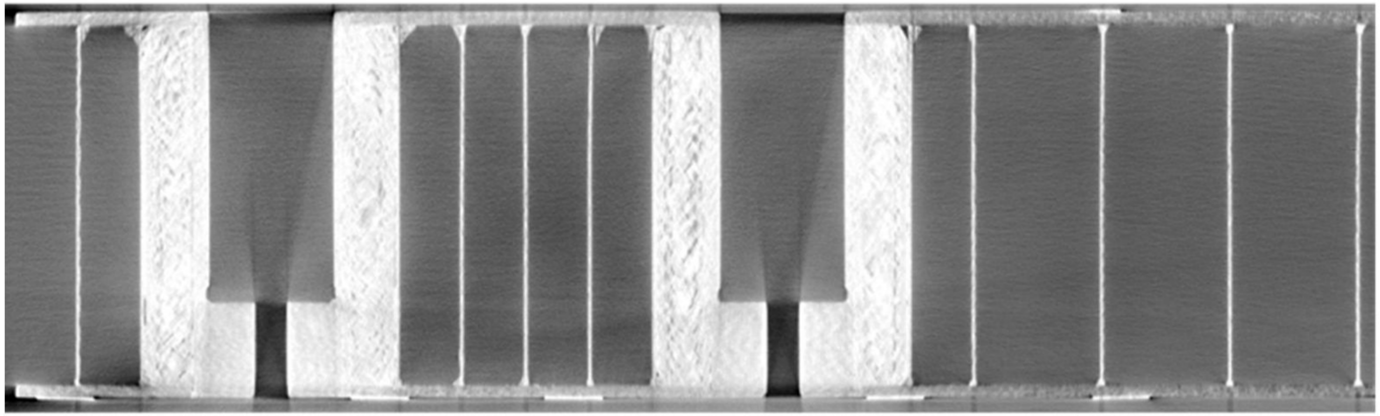
Attocube interferometric sensor

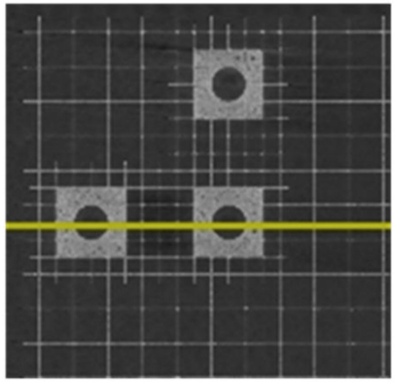
Mechanical Testing (TAS)

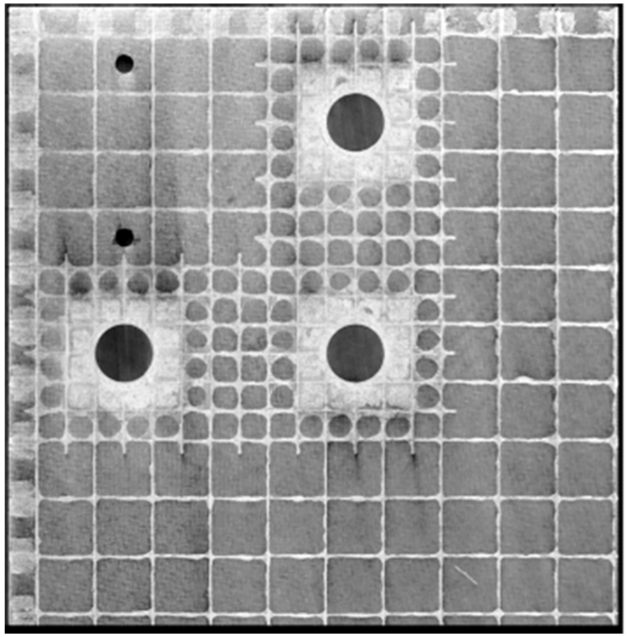
- Sine mode testing: QSL = 20g in Y, Z
- Random mode: OB qualified to
  - 40g in Z
  - High local loads in Y (bench/dummies: 200/55 g)
- Stiffness in compliance to simulation (180 – 250 Hz)
- 1st mode Y: 80 Hz < FEM :106 Hz (weak interface)

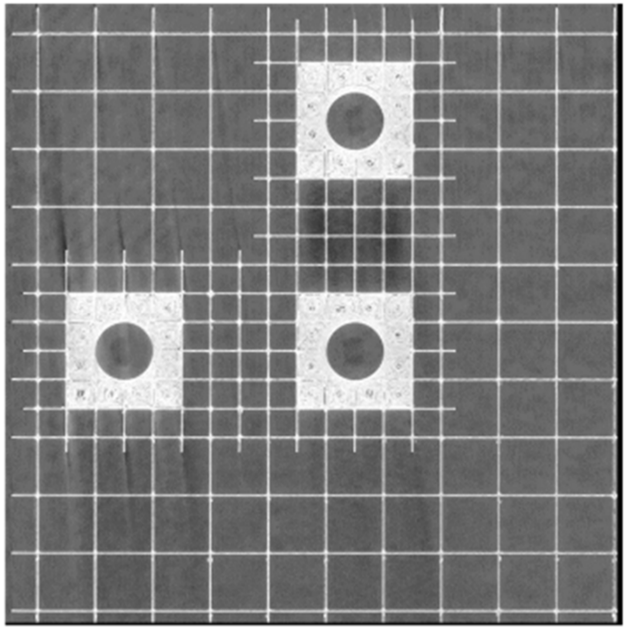


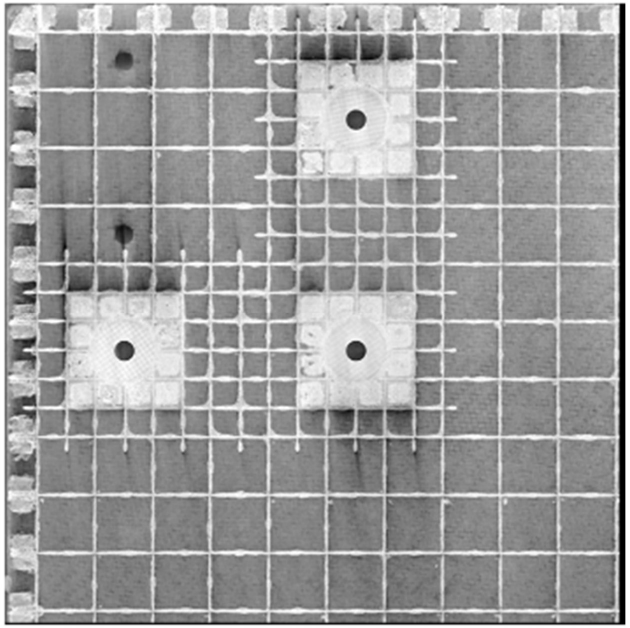
Integrity Testing (DLR)





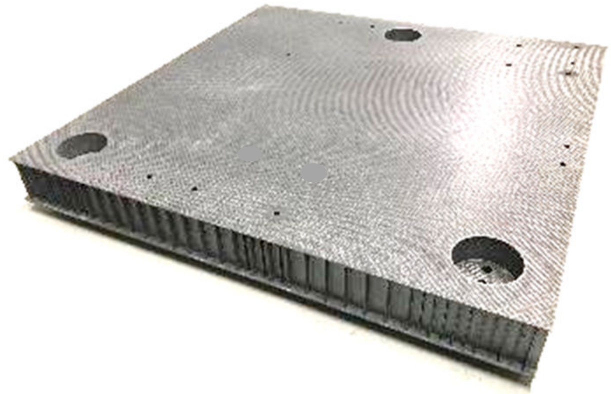




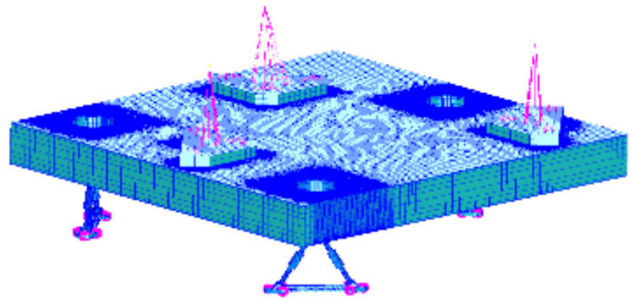


Summary

- C/C-SiC sandwich OB demonstrator developed in a close cooperation of DLR and TAS-F.
- Applicability of C/C-SiC sandwich for optical benches verified in a mechanical / thermal test campaign.
- Polymer free C/C-SiC interface concept qualified.
- FEM tool available for the design of C/C-SiC sandwich structures in future missions.
- QA procedure defined (process description, NDT).



- Open for applications beyond space (Charging carriers, heat exchangers, cooled chambers).



Acknowledgment

- Funding and support by ESA
  - TDE: C/C-SiC Sandwich Optical Bench development; Contract N.: 4000136973/22/NL/RA
  - NPI: Low Thermal Expansion and Highly Stiff Materials for Satellite Structures (LESSS) NPI 318-2013; Contract-No. 4000111641/14/NL/PA

- Teams at TAS-F and DLR

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