CYCLIC TESTING OF C/C-SIC SANDWICH STRUCTURES AND INTERFACES

DKG Jahrestagung

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DLR

Outline

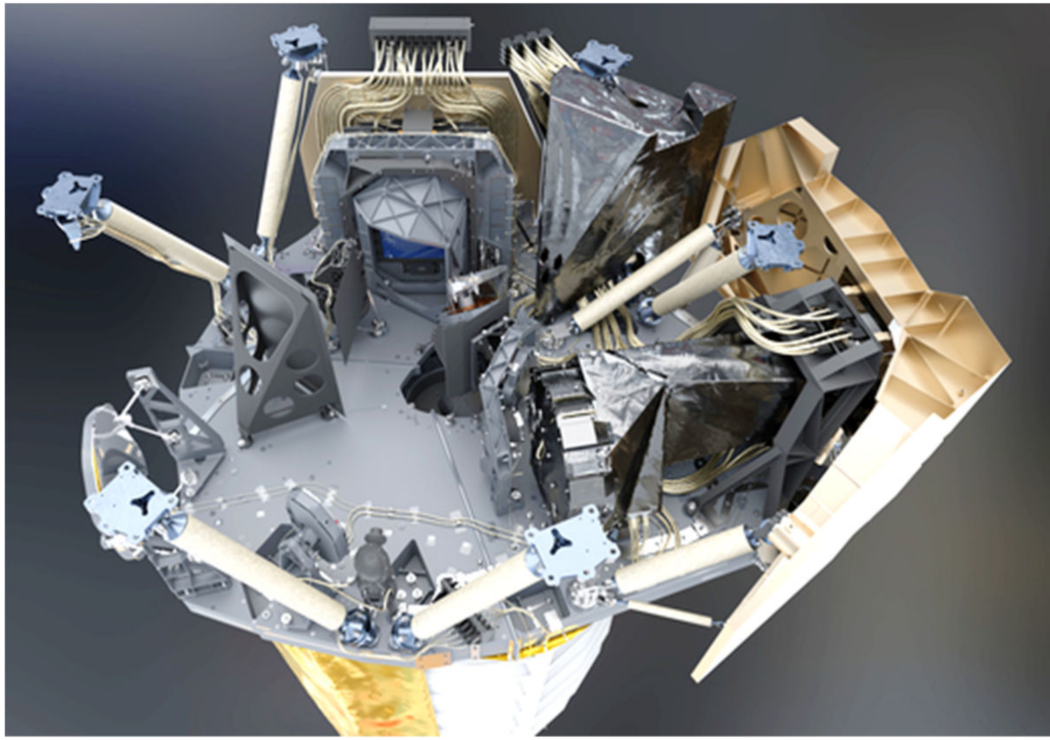
- Introduction
- C/C-SiC for optical benches
- Sandwich manufacture
- Testing
- Results
- Conclusion

Optical Benches (OB)

- Platform for laser systems and optical elements
- Very rigid for minimal deflection
- Stable alignment of optical elements
  - Temperature changes and moisture
  - Vibrations (launch, operation)
  - Long term space environment
  - Typical materials: SiC, Zerodur, CFRP sandwich, C/C sandwich

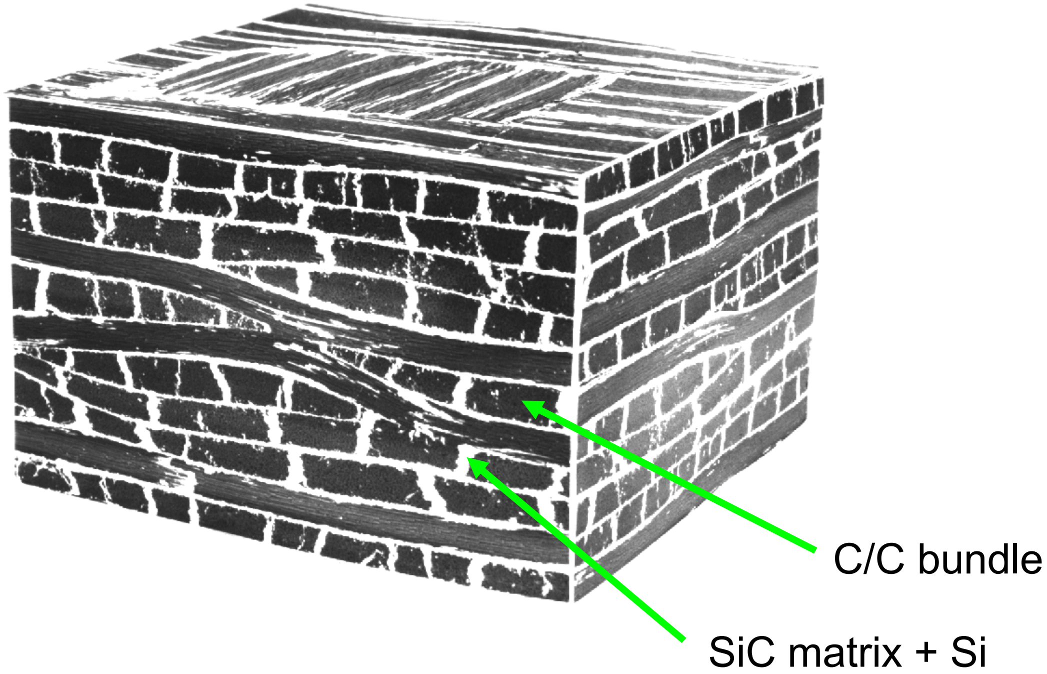
New approach:

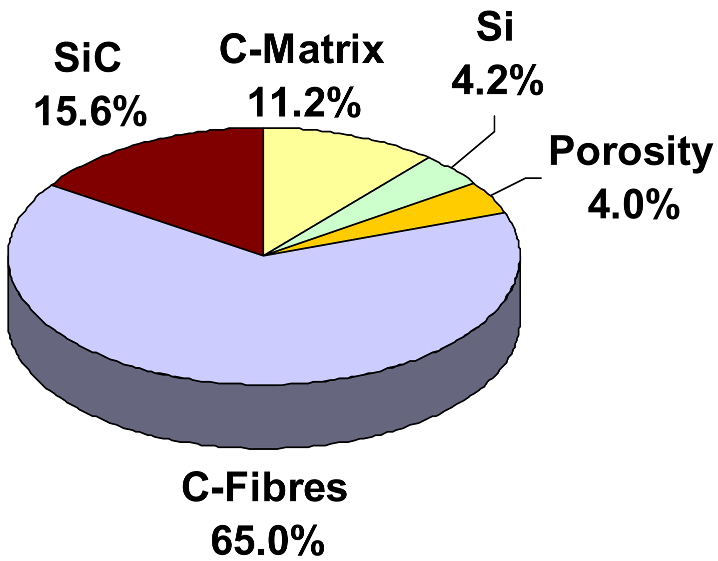
Ultrastable OB made of CMC sandwich structures (**C**eramic **M**atrix **C**omposites)



Optical Bench for Euclid, Airbus Defence and Space – Toulouse, 2018

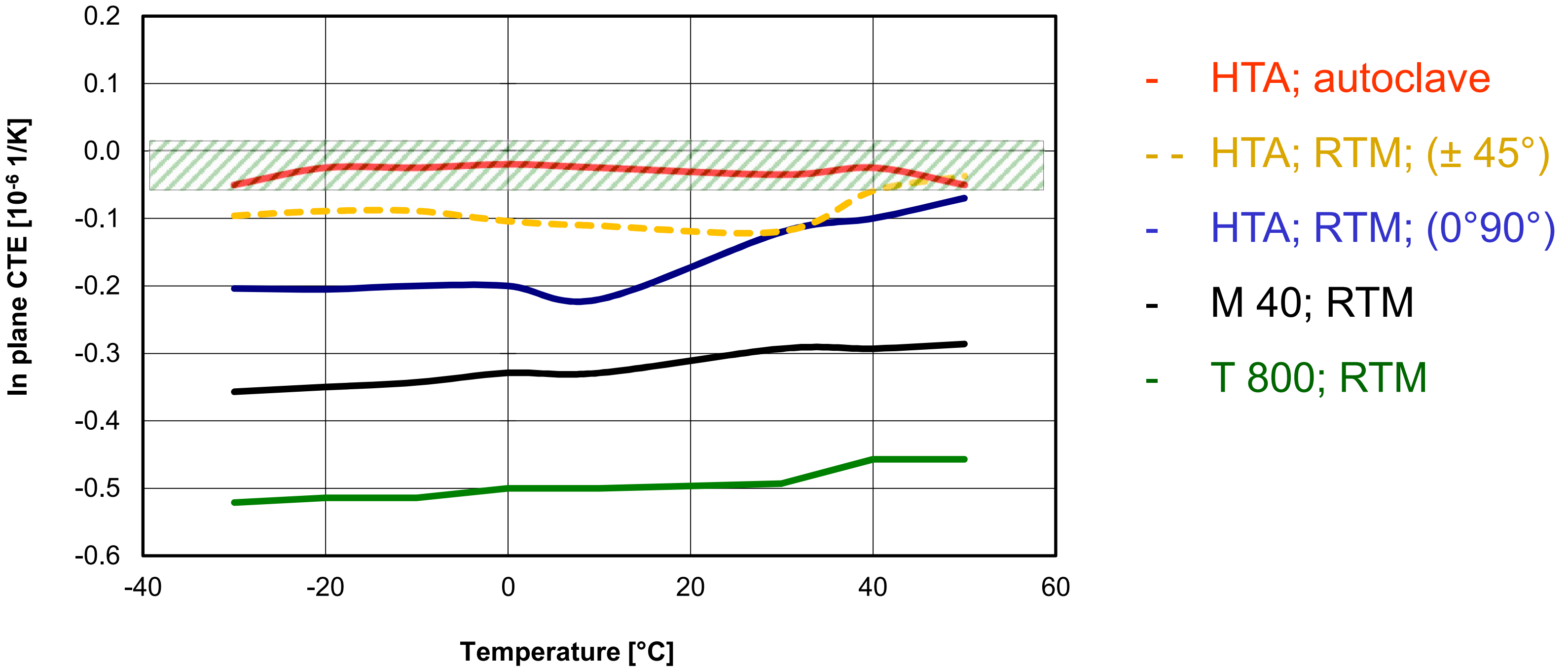
C/C-SiC Multiphase Material





CTE of C/C-SiC Materials

Fibre		HTA	T 800	M40J	YS-90-A-30S
CTE	10-6 K-1	-0.1	-0.56	-0.83	-0.5



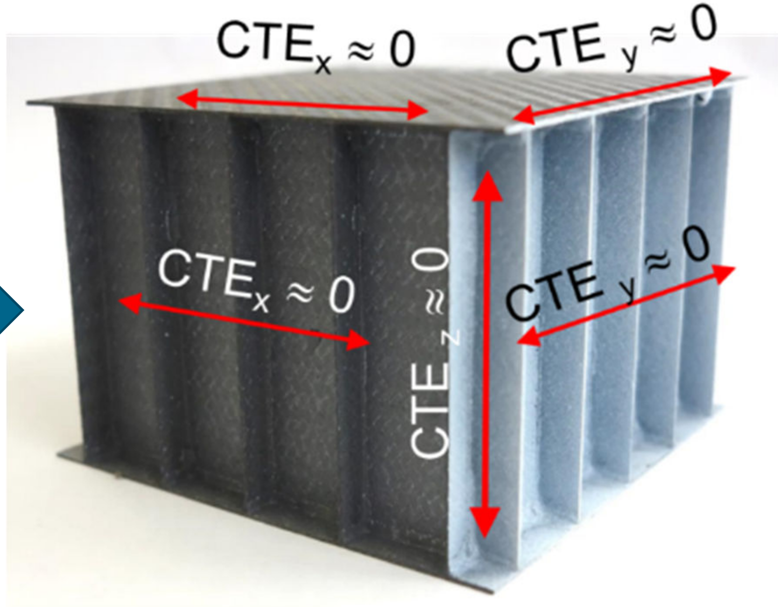
DIN 51045-1, DIN EN 821-1 (8x3x50 mm³)

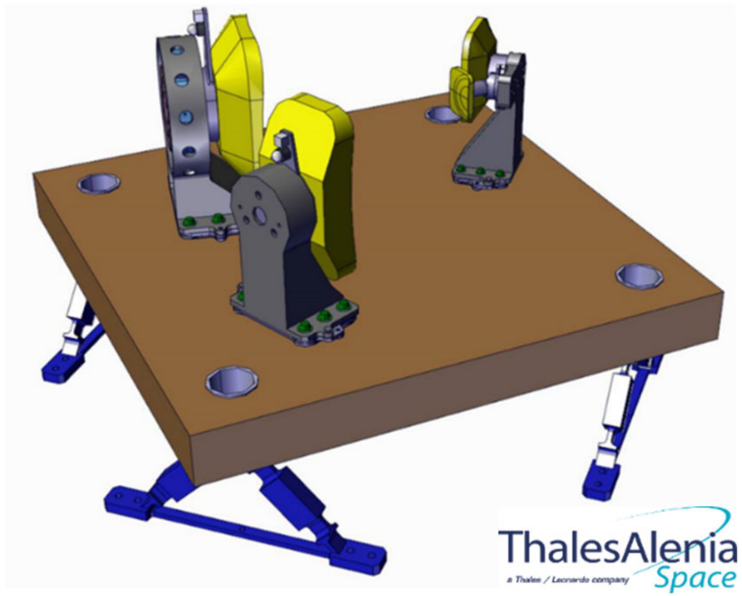
Renz, R.; Heidenreich, B.; Krenkel, W.; Schöppach, A; Richter, F.: *CMC Materials for Lightweight and Low CTE Applications,* 2001

C/C-SiC Sandwich Structures for Optical Benches

- Lightweight and highly stiff design
- 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

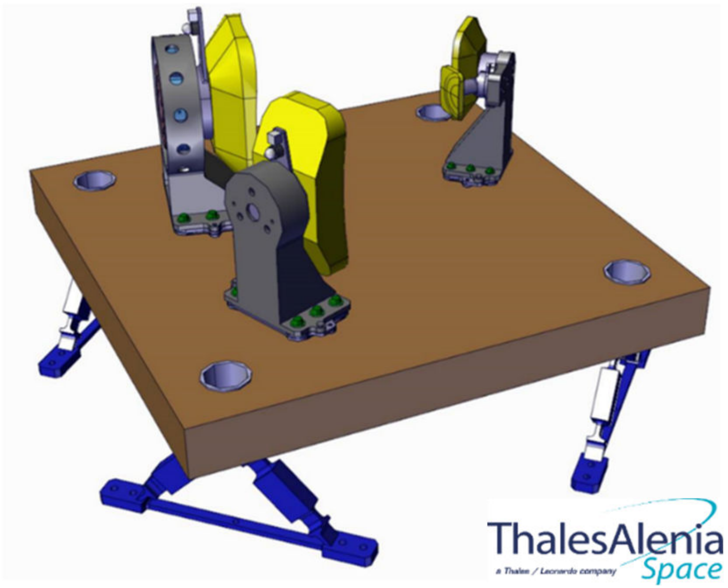
→ **Ultrastable optical benches for satellites**



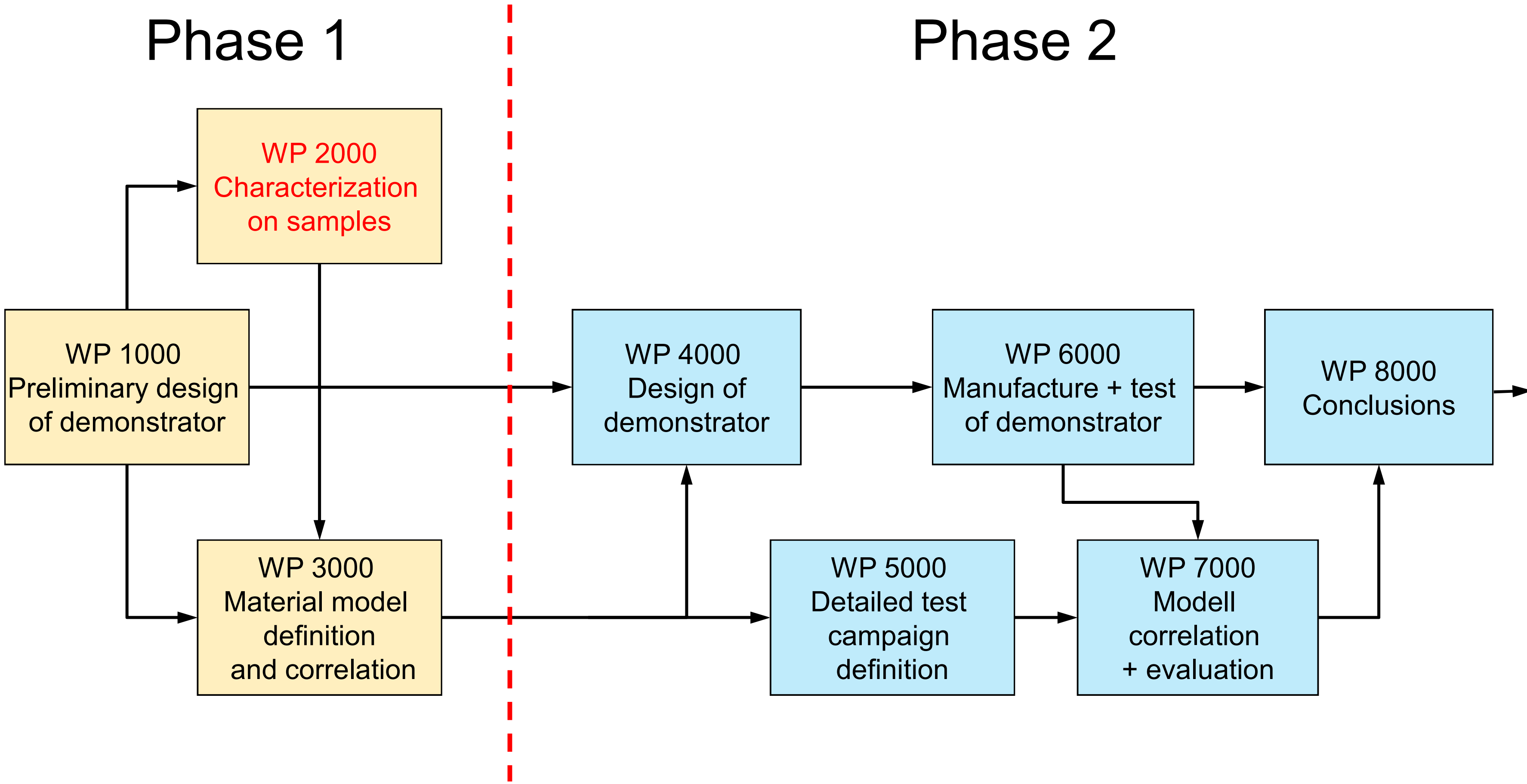


ESA TDE project: Development of a C/C-SiC Optical Bench Demonstrator (1)

- Sandwich structure ≥ 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 30g
- Natural frequency > 140 Hz



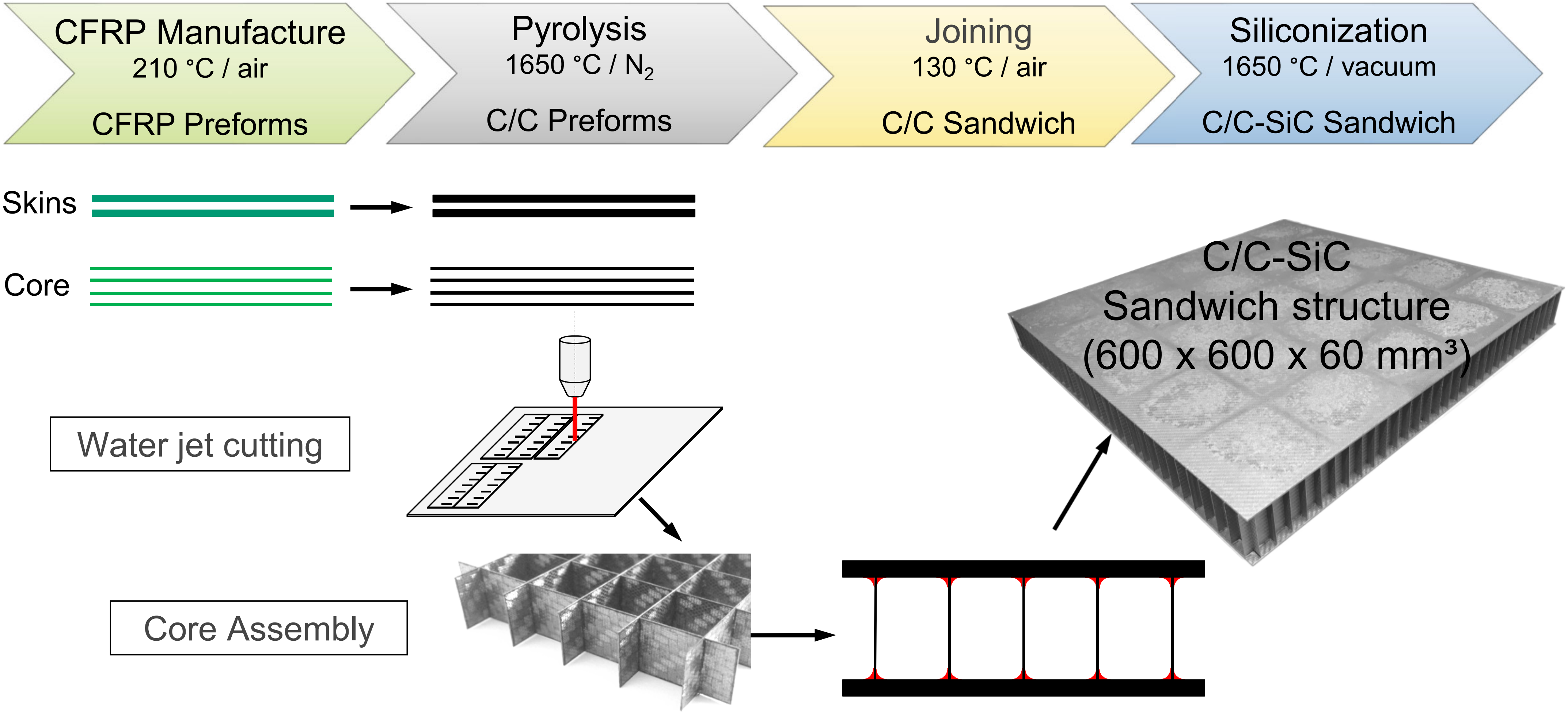
ESA TDE project: Development of a C/C-SiC Optical Bench Demonstrator (2)



C/C-SiC Sandwich Optical Bench

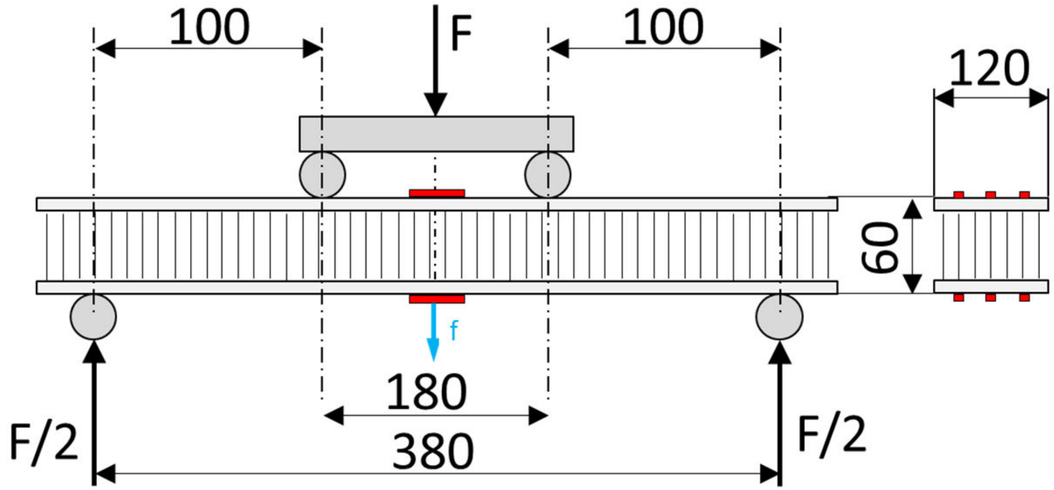
- Low CTE
- Structural integrity under dynamic loads an thermal cycling
- Numerical model

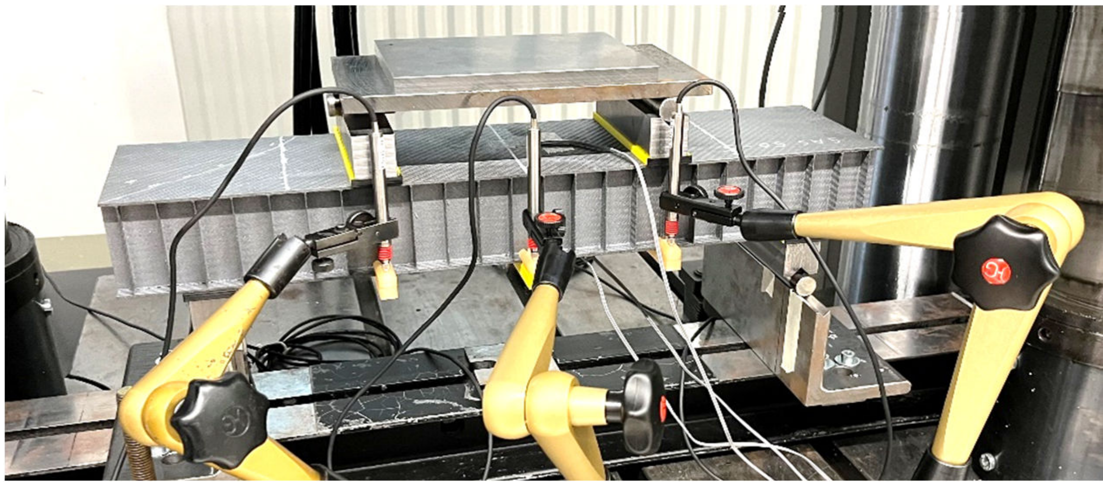
Manufacture of C/C-SiC Sandwich Structures



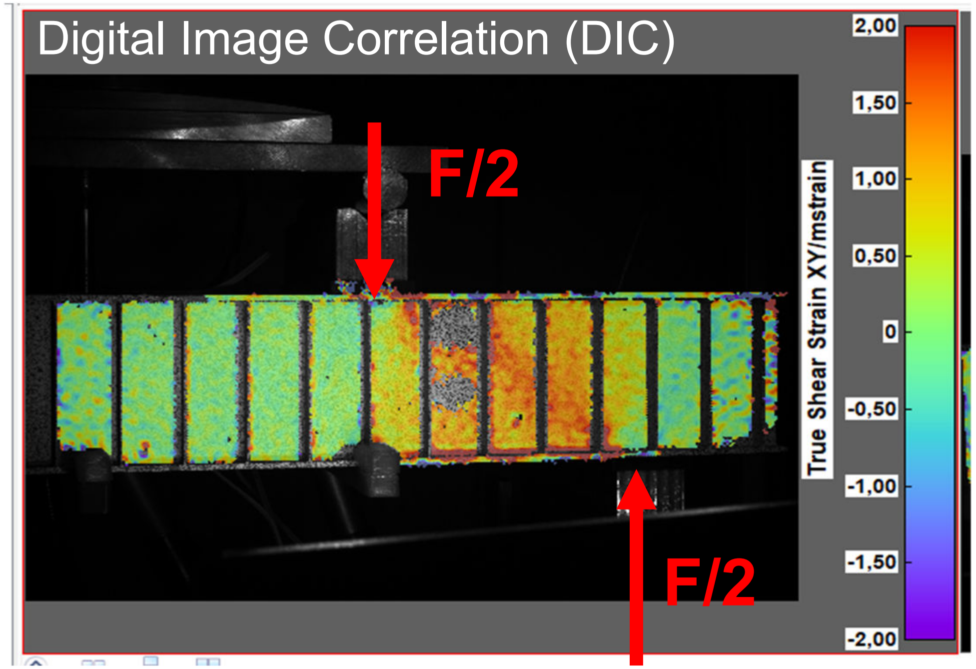
Bending Test of Sandwich Samples and Structures

- 4-Pt. Bending according to DIN 53239
- Modelling and FEM simulation for sample geometry definition
- Accurate measurement of displacements (LVDT; Linear Variable Differential Transformer)
- Quasistatic cyclic testing → mechanical stability





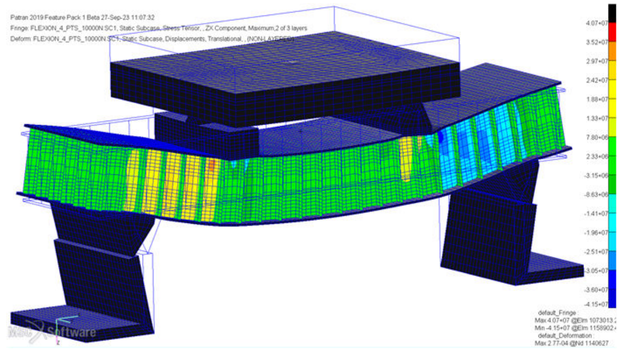
Failure Mode

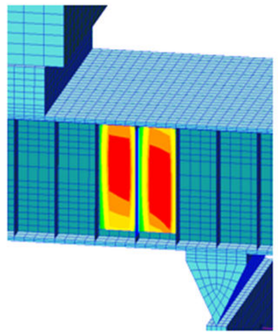


- F u = 22.3 ± 3.1 kN → Shear failure of core web in in all samples in critical load span, followed by local core/skin debonding.
- Sudden failure, but quasiductile fracture behaviour

Results

			Theo-retical	Test Mean	Test Deviation	FEM F=22 kN
Failure Load	F_u	[kN]	20.0	22.3	3.1	
Displacement at ultimate load	f_u	[µm]	1 185	940	141	610
Ultimate shear stress in webs	$\tau_{web,u.}$	[MPa]	71.7	82.8	11.4	80
Shear strength	$\tau_{web,allowable.}$	[MPa]		71.7		
Ultimate tension stress in skin	$\sigma_{skin,\ u}$	[MPa]	74.2	82.7	11.4	
Tensile strength	$\sigma_{skin,\ allowable}$	[MPa]		86.0		

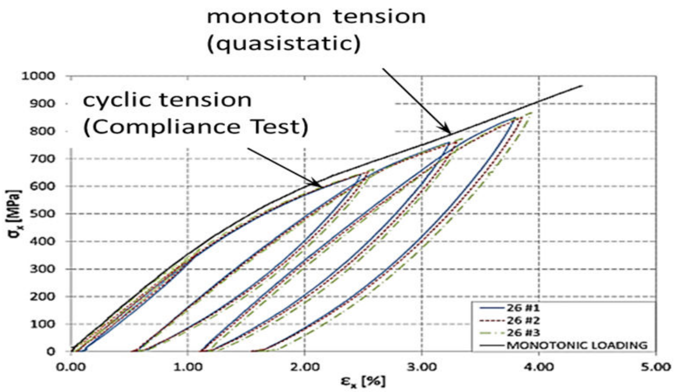




- Maximum stresses in skins and core webs close to material strengths → well-balanced design
- FEM predicts shear failure in accordance with test
- Deviations in displacement due to deviations of set-up, tilting of sample, linear instead of non-linear calculation

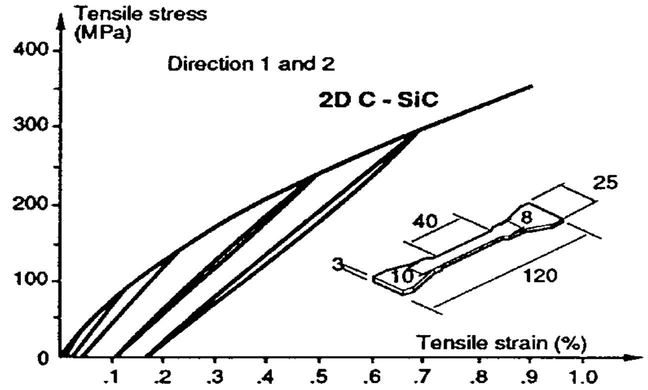
Cyclic Testing of Composites

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]

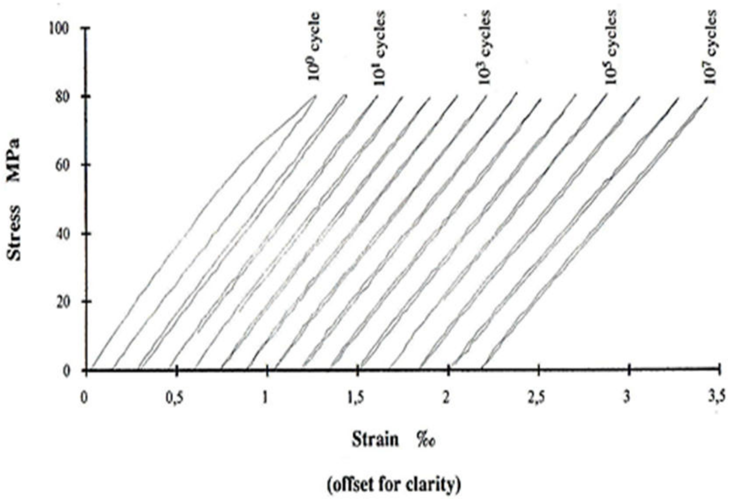
C/SiC



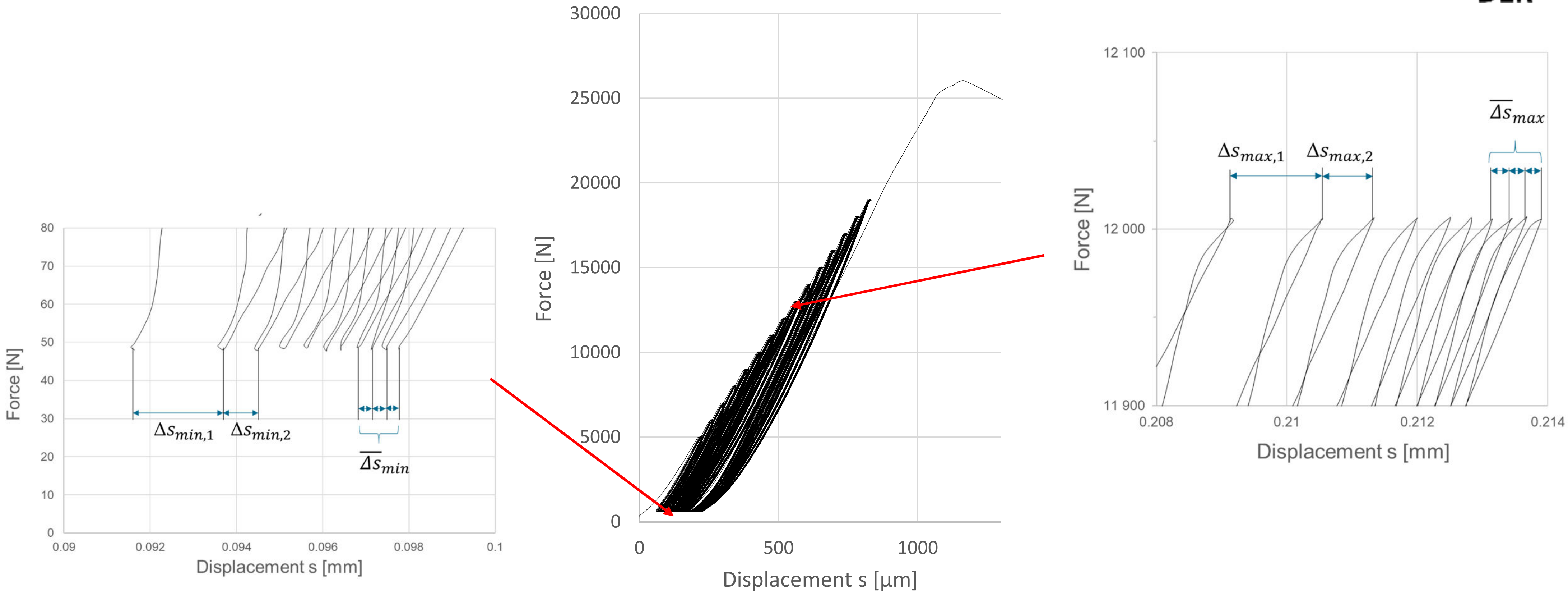
D. Desnoyer, A. Lacombe, J.M. Rouges, *Large Thin Composite Structural Parts*, Proceedings of International Conference Spacecraft Structures and Mechanical Testing, Nordwijk, The Netherlands, 1991]

C/C-SiC

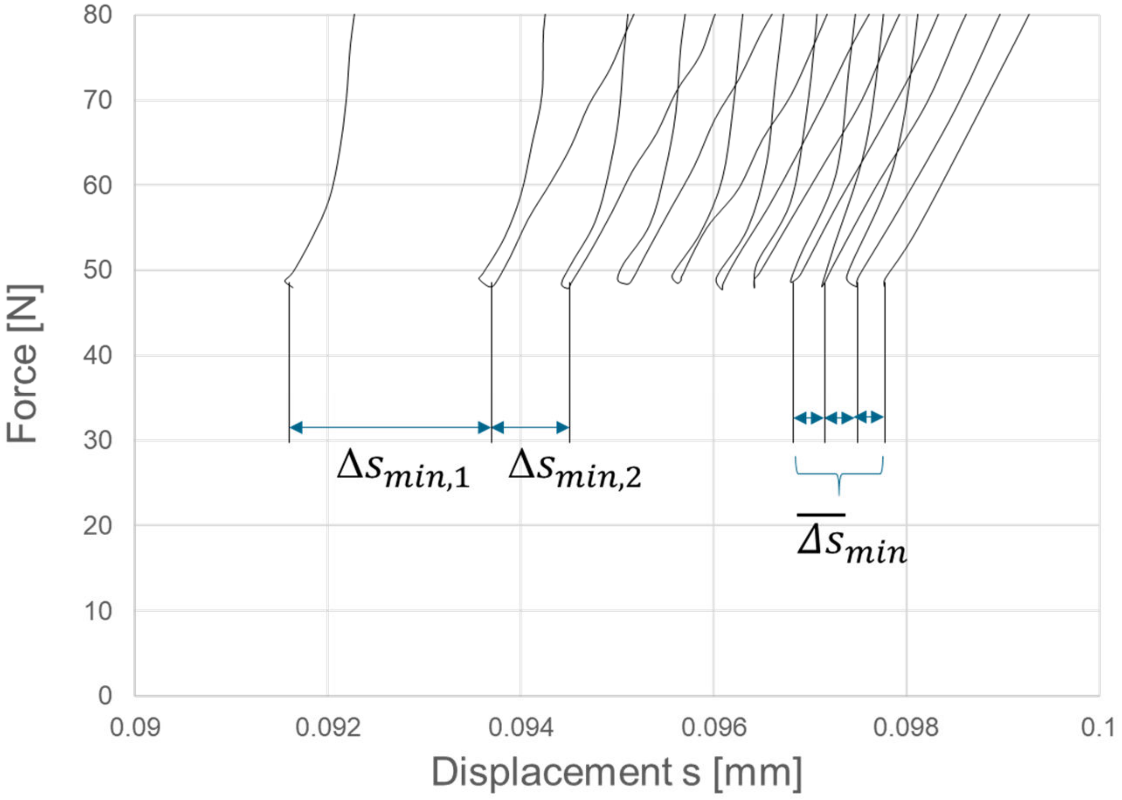
[Kochendörfer, 2000]

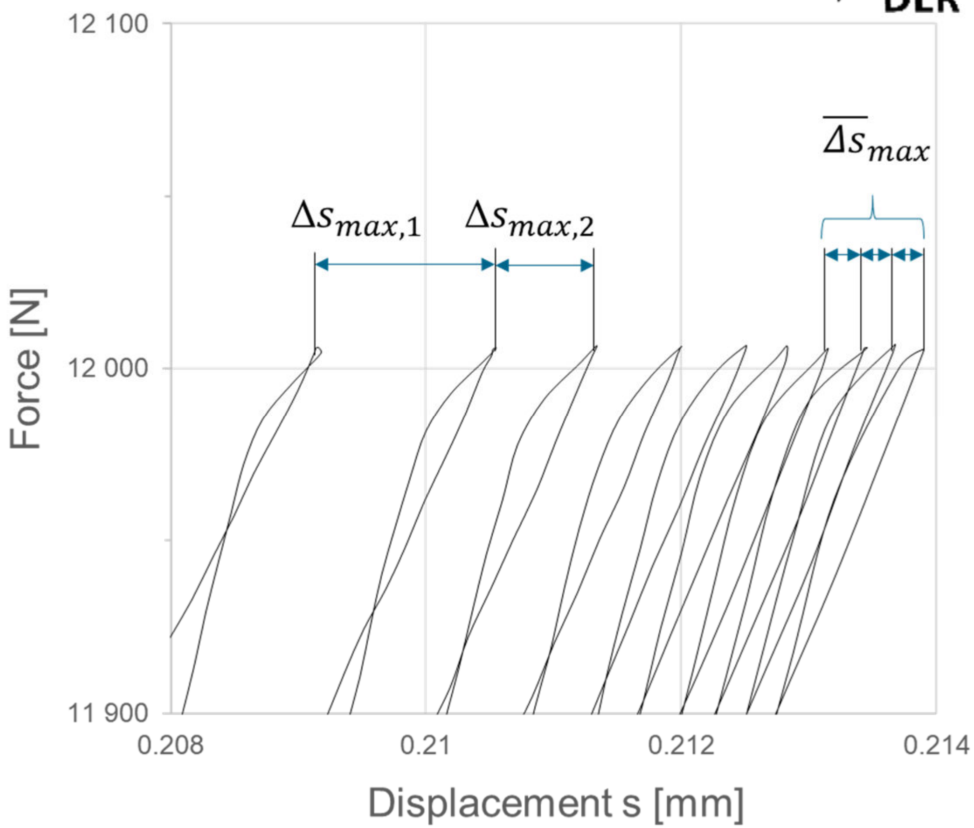


Cyclic Testing of C/C-SiC Sandwich



Cyclic Testing of C/C-SiC Sandwich

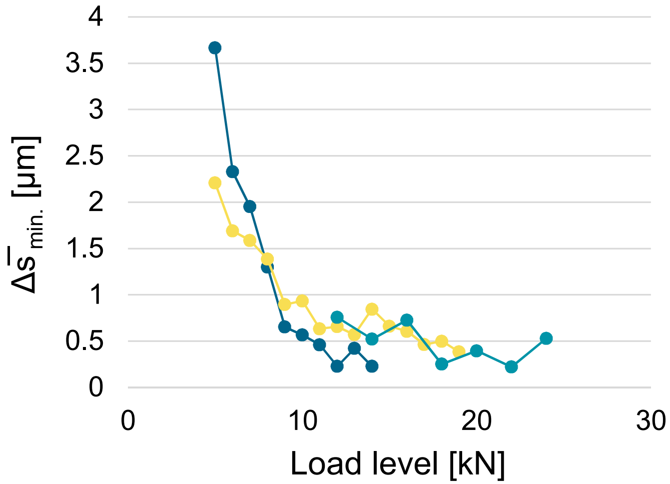


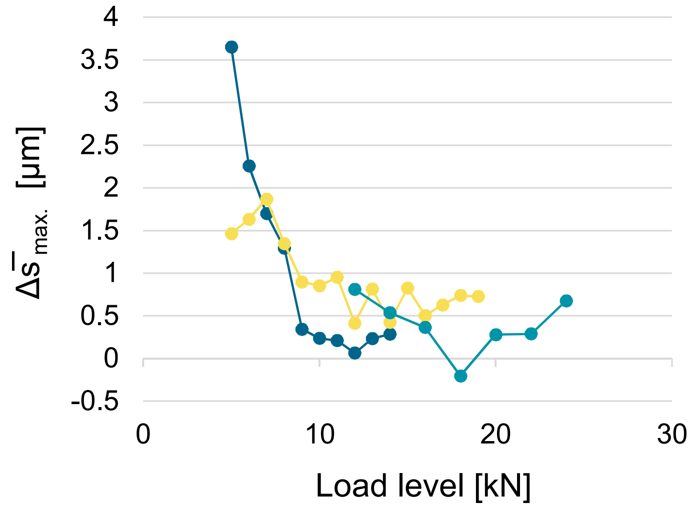


Stable structure <=> s = constant <=> Δ s = 0 ; $\overline{\Delta s} = 0$

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 did not evolve anymore



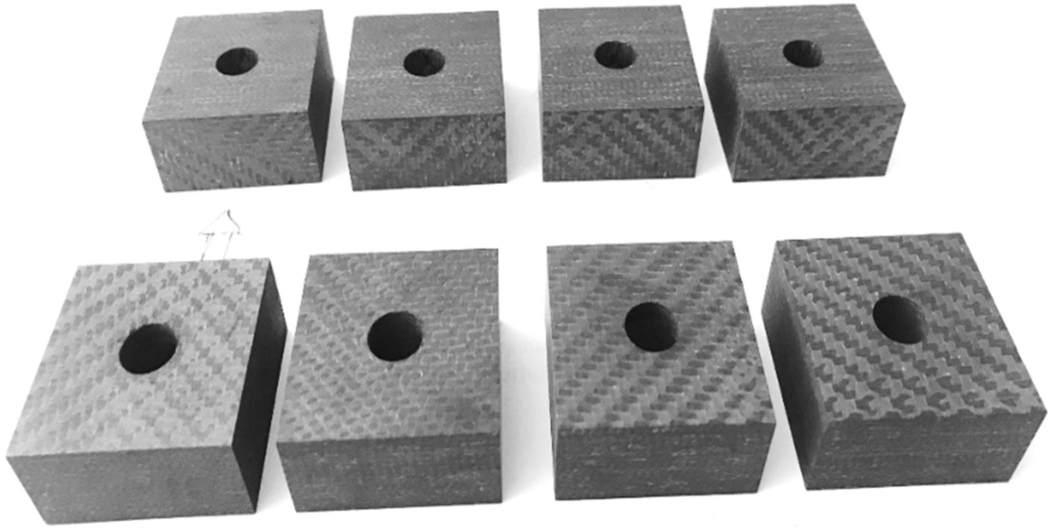


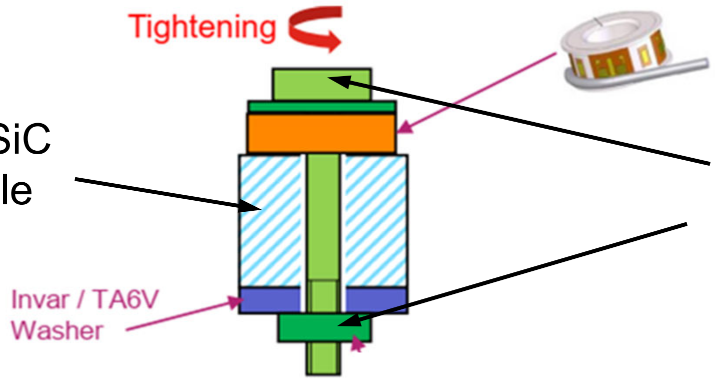
→ C/C-SiC sandwich is stable after preloading

Screw Tightening Test for Screwed Interfaces

Coupons ∥
boring parallel to fabric laminate

Coupons ⊥
boring perpendicular to fabric laminate

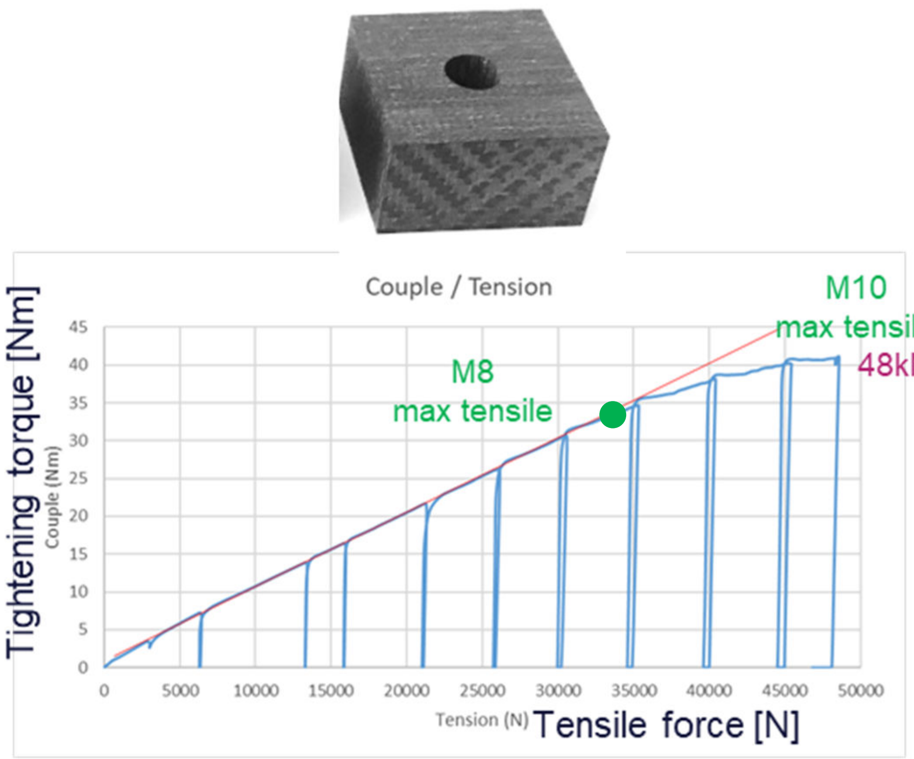


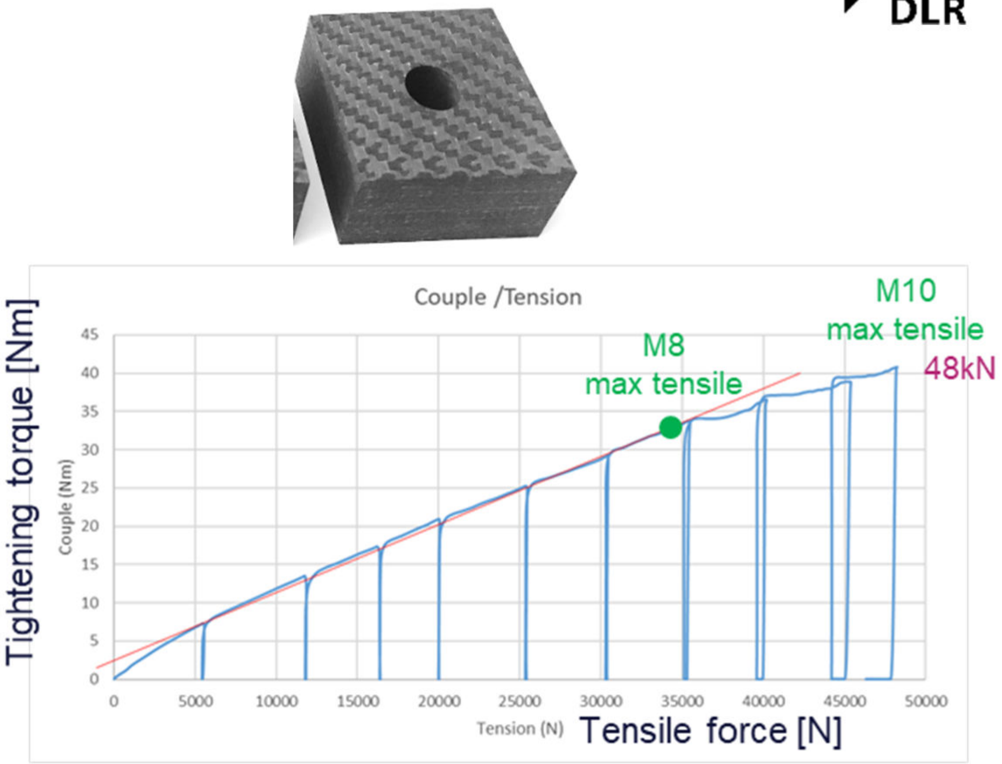


C/C-SiC
sample

M10 Titanium screw and nut
Maximum screw tension force: 48 kN

Screw Tightening Test Results





- A maximum screw tension of 48 kN was applied without any degradation (7 days).
- The non-linearity observed is well known (plastic deformation in the thread of the Ti-nuts)

Summary

- A C/C-SiC sandwich OB demonstrator in subscale geometry, was developed successfully in cooperation of DLR and TAS-F.
- Successful sample tests of the sandwich structure and the screwed interface concept demonstrated:
  - the reproducible manufacturing with a very good core to skin bonding
  - the expected mechanical strength (even better)
  - the high stability of sandwich structure and material
- The material model and simulation reproduced closely real structural behaviour / conservative failure criteria obtained.
- Next step: Thermal and mechanical test of C/C-SiC sandwich demonstrator at TAS-F, Cannes.