Influence of Fiber Type on the Properties of Short-Fiber Based C/C-SiC

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Content

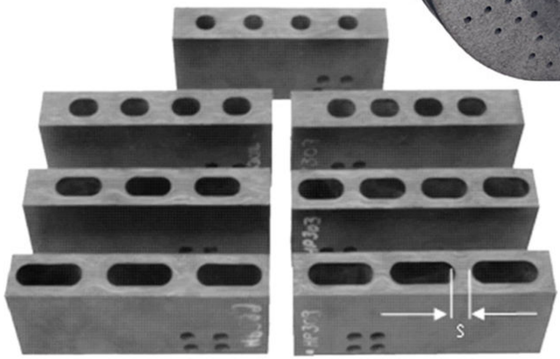
- Introduction
- Manufacture of short fiber based C/C-SiC materials
- Material properties
- Mechanical properties in tension and 4-pt- bending
- Conclusion
- Outlook

General Properties of Short Fiber Based C/C-SiC (C/C-SiC SF)

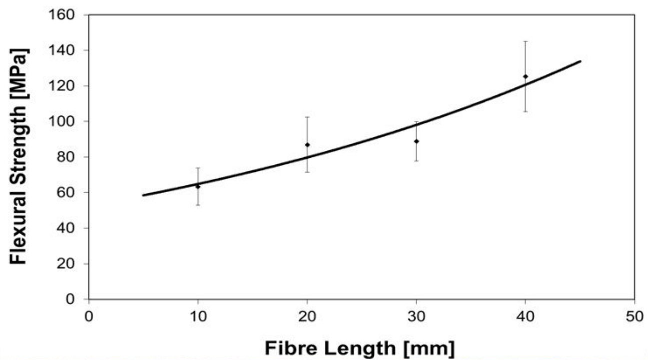
Porsche AG, 2004

Compared to C/C-SiC based onfabric (2D) or 3D fiber preforms, C/C-SiC SF offer

+ Near net shape manufacture of higly complex parts
+ Randomly oriented fibers with „3D“ fiber architecture
  - → low risk of delamination → fast processes
  - → higher out of plane strength
+ Low cost fiber preform (no weaving, automatized cutting)
+ High availability of all fiber types



\- Lower in plane strength, because:
  - fibers not oriented in load direction
  - limited fiber length



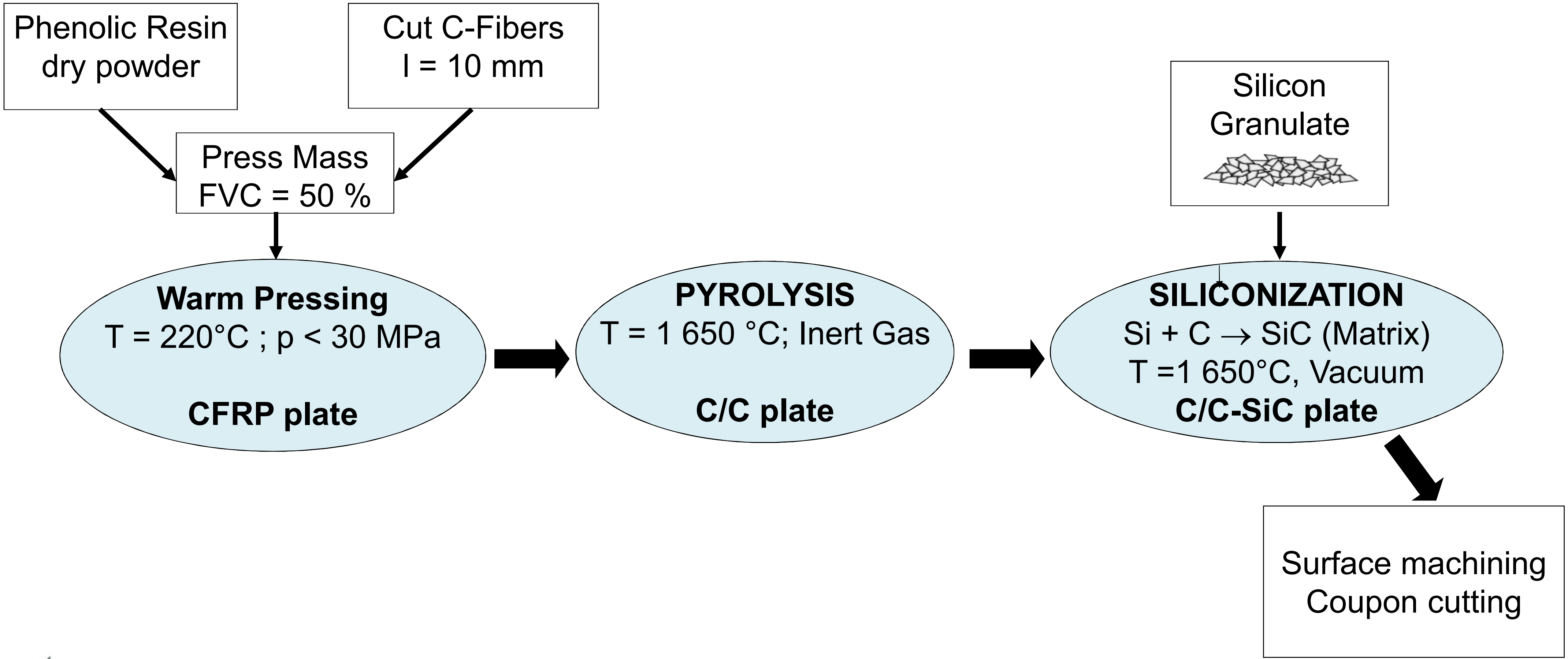
B. Heidenreich, R. Renz, W. Krenkel, *Short Fibre reinforced CMC Materials for High Performance Brakes*, in *High Temperature Ceramic Matrix Composites*, W. Krenkel, R. Naslain, H. Schneider, Eds., Wiley-VCH, Weinheim, Germany, p. 809 - 815 (2001).

New Approach

Increase of mechanical properties of C/C-SiC SF by:

- Replacing standard HT fibers by high performance carbon fibers
- Orientation of the fibers in load direction
- Homogeneous fiber distribution by defined mould loading strategy

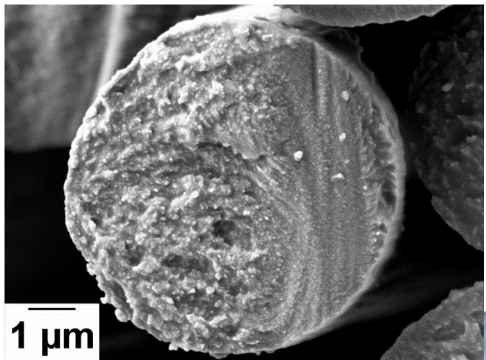
Manufacture of C/C-SiC SF via Liquid Silicon Infiltration (LSI)

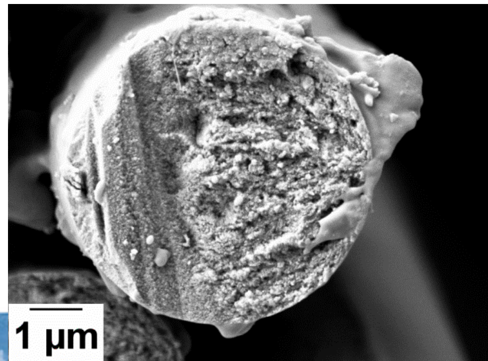


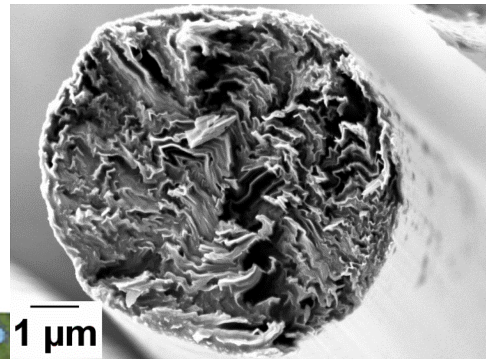
Carbon Fiber Types

Fibre		HTA (Tenax HTA 40 E13)	T800 (T800H)	YS 90 (Granoc YS-90A-30S)
Fiber grade		1K / 6K	12K	3K
Manufacturer		Tejin	Toray Composite Materials America	Nippon Graphite Fibres (NGF)
Fibre precursor		PAN	PAN	Pitch
Tensile strength	[GPa]	4.1	5.49	3.53
Young‘s modulus	[GPa]	240	294	880
Ultimate strain	[%]	1.7	1.9	0.3
Filament diameter	[µm]	7	5	7
Fiber cost (2022)	[€/kg]	50 / 260	145	1 200

+ 34 %







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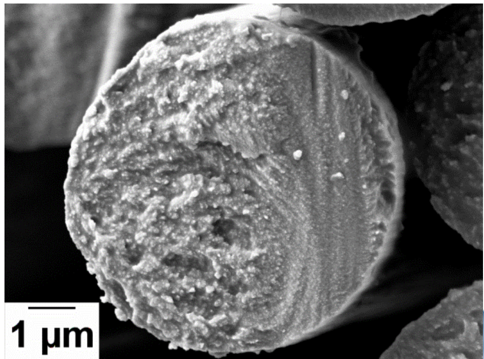
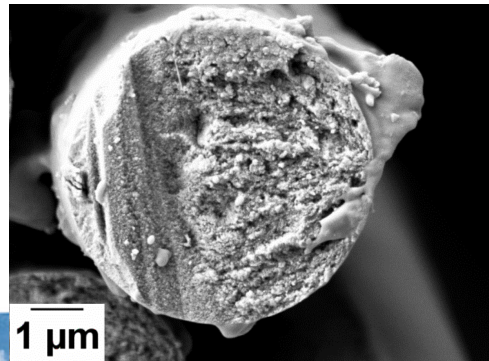
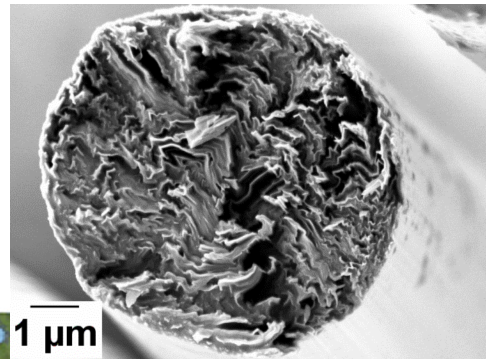
x 3.7







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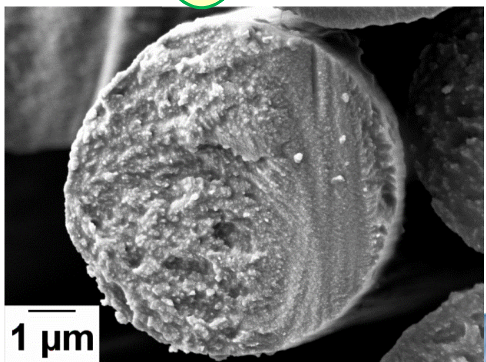
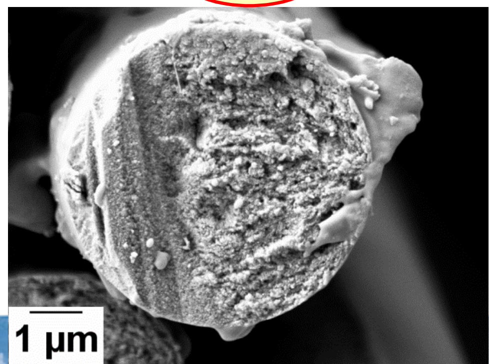
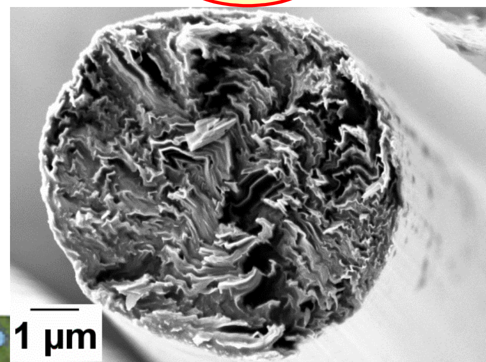
x 2-3

x 6 - 8

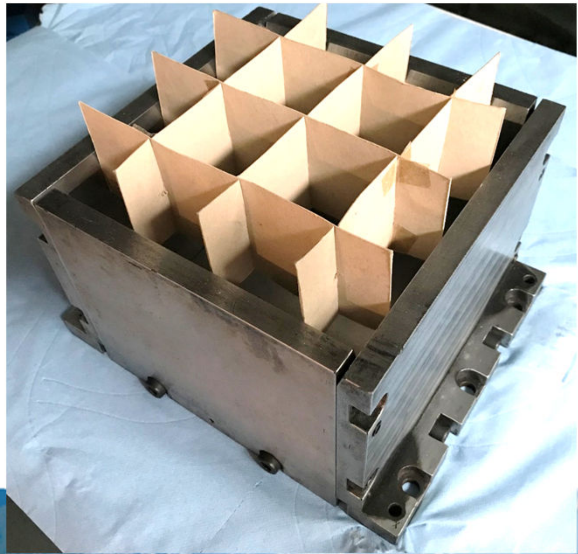






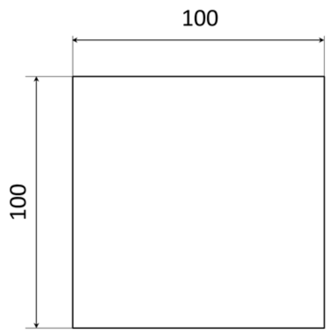
Mould Loading and Fiber Orientation

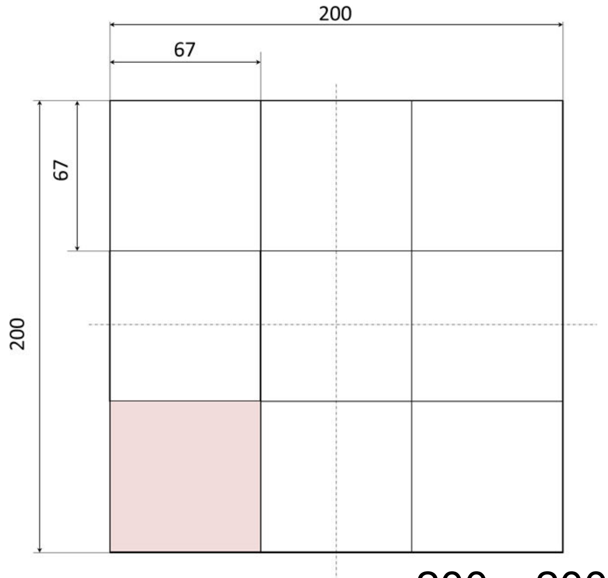
- Small moulds are filled with one press mass batch in whole area (100 x 100 mm²).
- Bigger moulds are difficult to fill homogeneously → splitting mould area in multiple loading cells.
- Reduce fiber alignment by multiple layers and overlapping loading cells.
- Orientation of short fibers by using narrow loading cells (w = 10 mm).

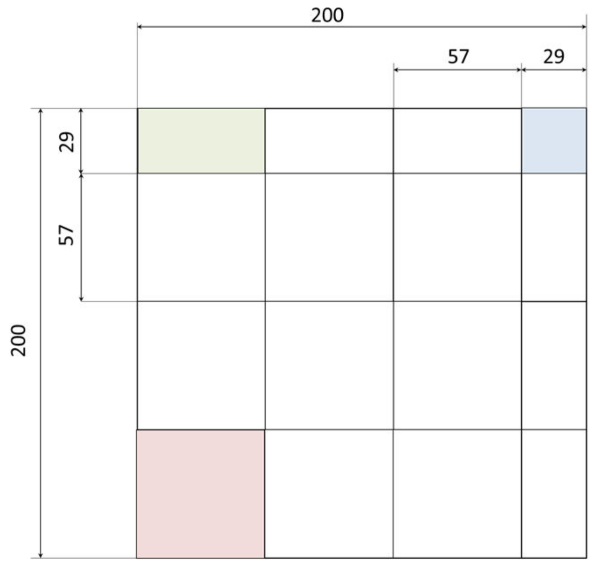


Loading Methods - Randomly Oriented Fibers

	Single batch For small plates	Multiple batches no overlap	Multiple batches overlap







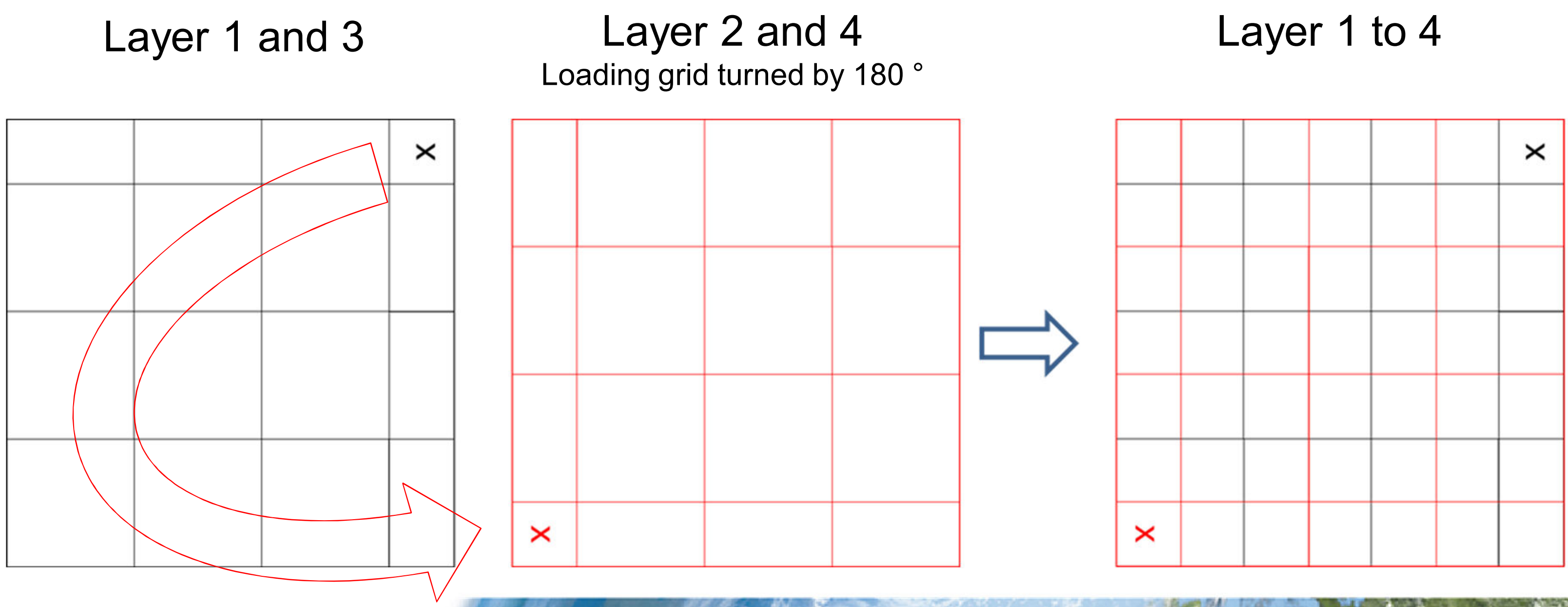
	Single batch	no overlap	overlap
CFRP plate	100 x 100 x 4 mm³	200 x 200 x 6 mm³	
Loading cell	100 x 100 mm²	67 x 67 mm²	57 x 57; 57 x 29; 29 x 29 mm²
Nomenclature	100 ²	67 ²	29 ²
No. of layers / portions	1 / 1	1 / 9	4 / 64

Loading Methods - Multiple Batches with Overlap

- 4 layers
- Grid turned after each layer

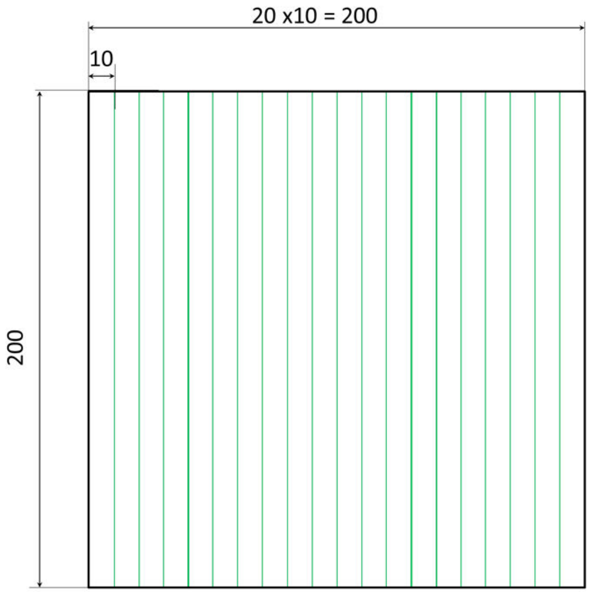
⇨

- 50 % overlap of cells
- small cells 29 x 29 mm²

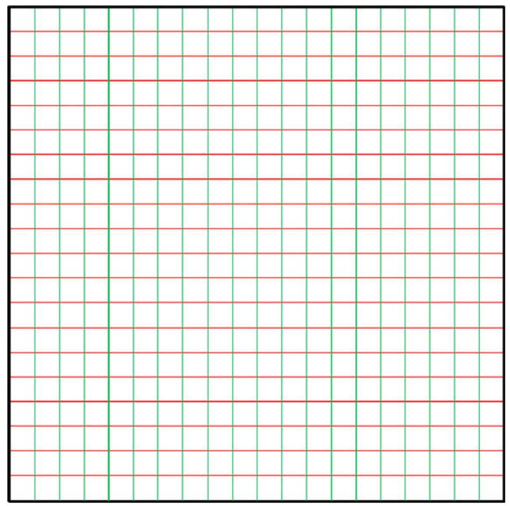


Loading Methods - Unidirectional Oriented Fibers

0° - UD



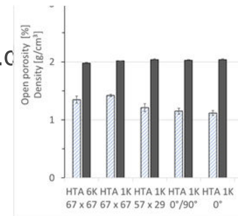
0° / 90° - UD crossply
(0° / 90° / 90° / 0°)



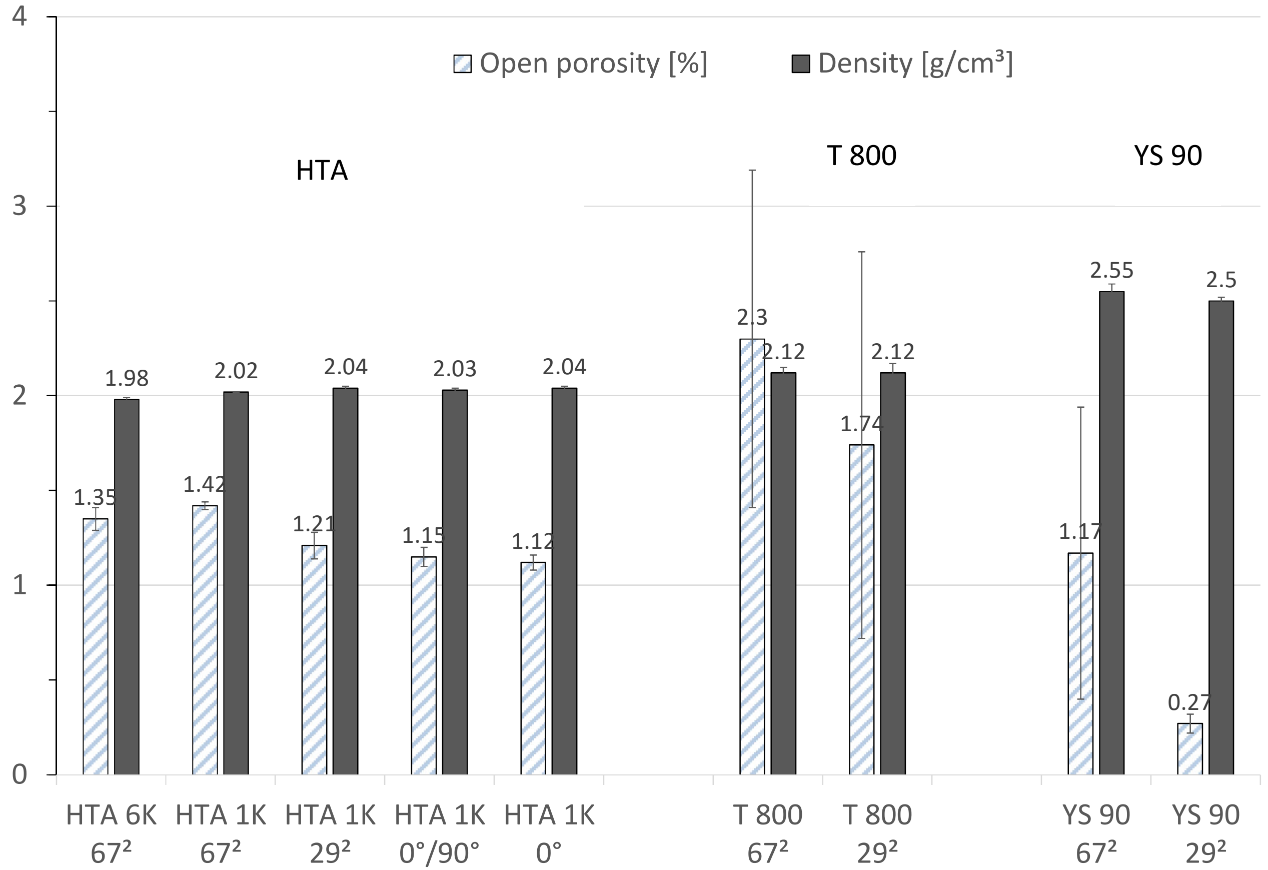
	0° - UD	0° / 90° - UD crossply
CFRP plate:	200 x 200 x 6 mm^3	200 x 200 x 6 mm^3
Loading cell:	10 x 200 mm^2	10 x 200 mm^2
Nomenclature	0°	0° / 90°
No. of layers / batches:	1 / 20	4 / 80

Sample overview

		HT 1K		HT 6K	HT 1K				UHT			UHM		
Fiber type	[-]	**HTA 40**							**T800HB 12000-40B**			**YS-90A-30S**		
Fiber manufacturer		**Tejin Carbon**							**Toray**			**NGF**		
CFRP plate geometry	[mm]	100^2 x 4	200^2 x 6						100^2 x 4	200^2 x 6		100^2 x 4	200^2 x 6	
Fiber orientation	[-]	random				0°90°	0°		random			random		
Filling method														
Grid size	[mm]	100 x 100	67 x 67		29 x 29	10 x 200			100 x 100	67 x 67	29 x 29	100 x 100	67 x 67	29 x 29
Number of layers	[-]	1			4	4	1		1		4	1		4
Number of portions	[-]	1	9	9	64	80	20	20	1	9	64	1	9	64
Fiber content in CFRP	[Vol.-%]	49.4	47.5	48.4	47.5	47.9	47.5	48.3	49.0	46.7	46.9	48.8	48.0	40.6

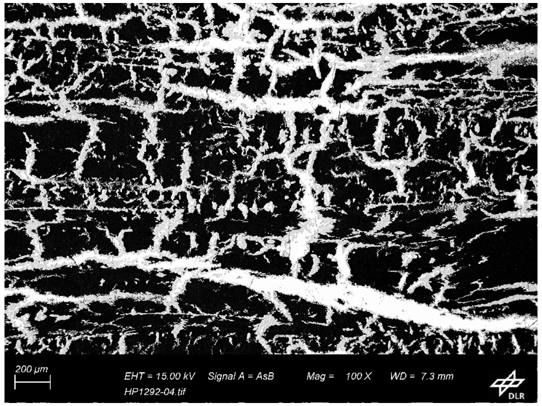


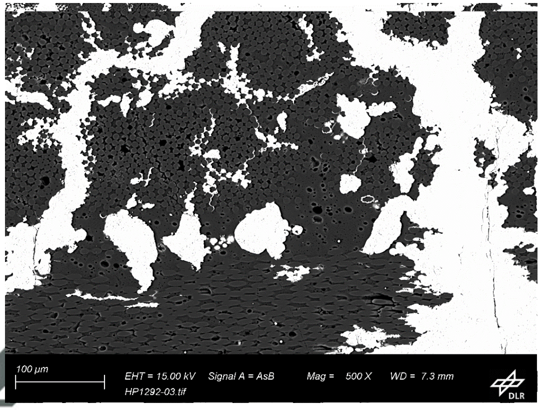
C/C-SiC Material properties – Porosity and Density



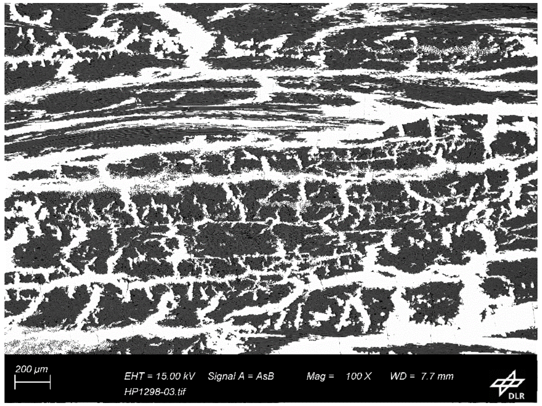
Material properties – Microstructures and Phase Contents (SiC / Si / C)

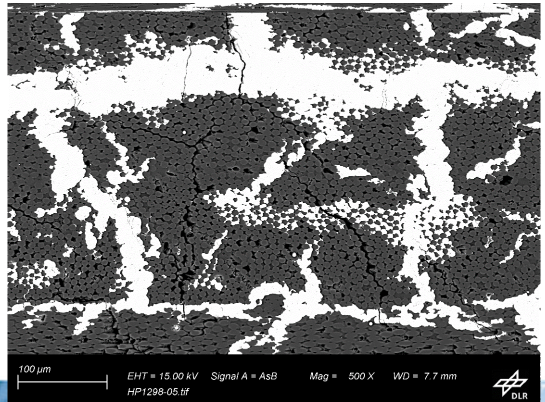
HTA (1K)
26 / 10 / 64



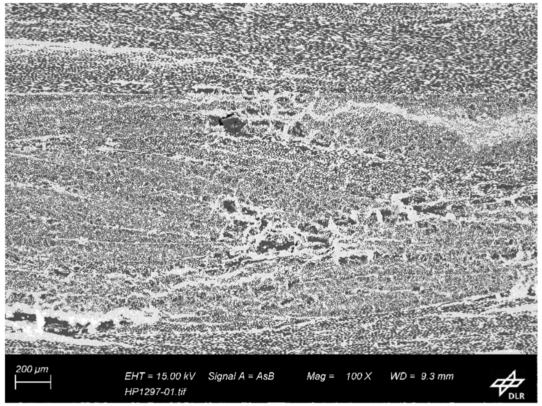


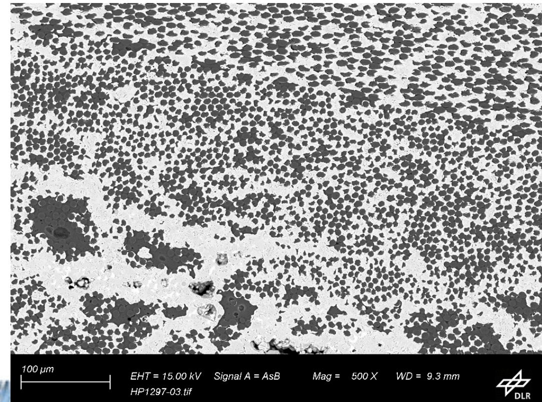
T 800
28 / 8 / 64





YS 90
49 / 4 / 47





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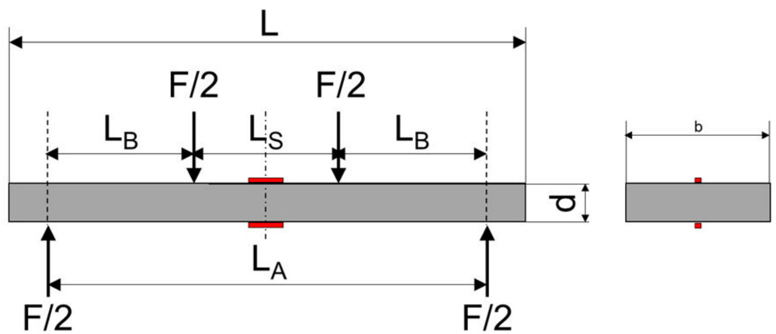
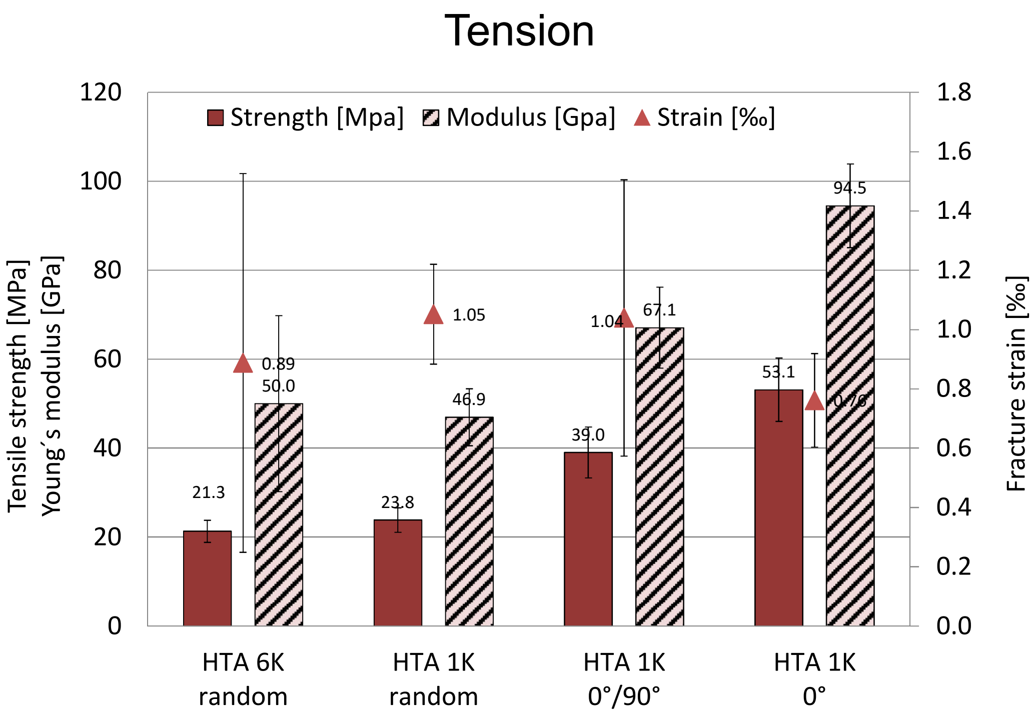
Coupon Testing

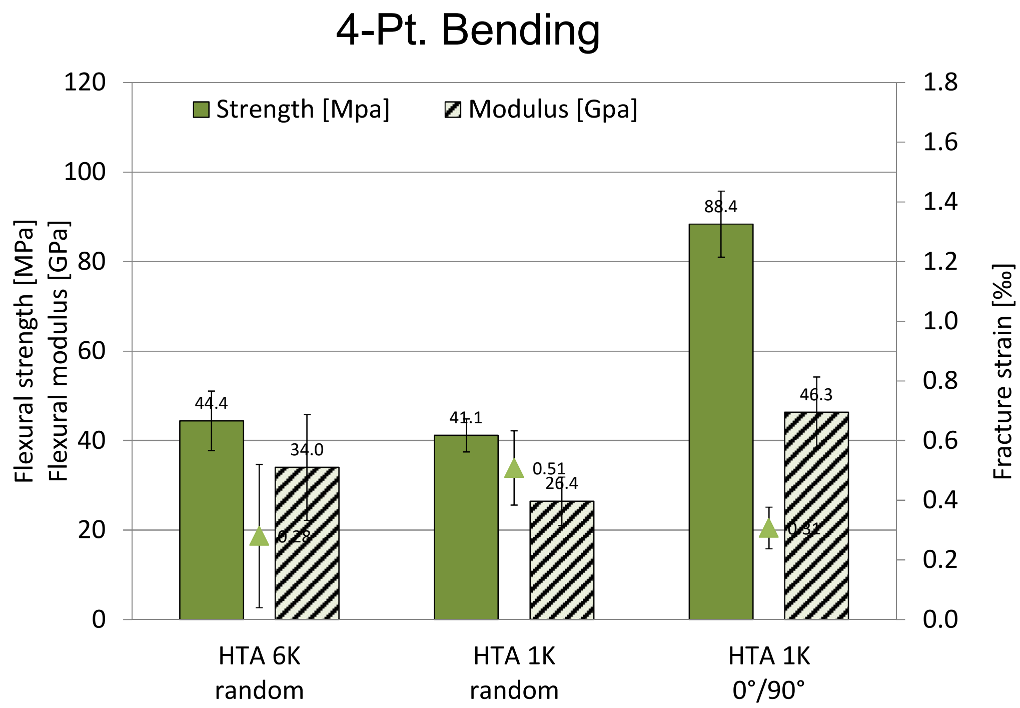
- 4-Pt. Bending
  - 100 x 18 x 2.8 mm³ — L_A = 76 mm; L_S = 20 mm — $(L_A - L_S)/d = 20$
  - 110 x 20 x 4 mm³ — L_A = 100 mm; L_S = 20 mm — $(L_A - L_S)/d = 20$



- Tension
  - 120 x 20 x 4 mm³

Influence of Fiber Grade (HTA 1K / 6K) and Fiber Orientation

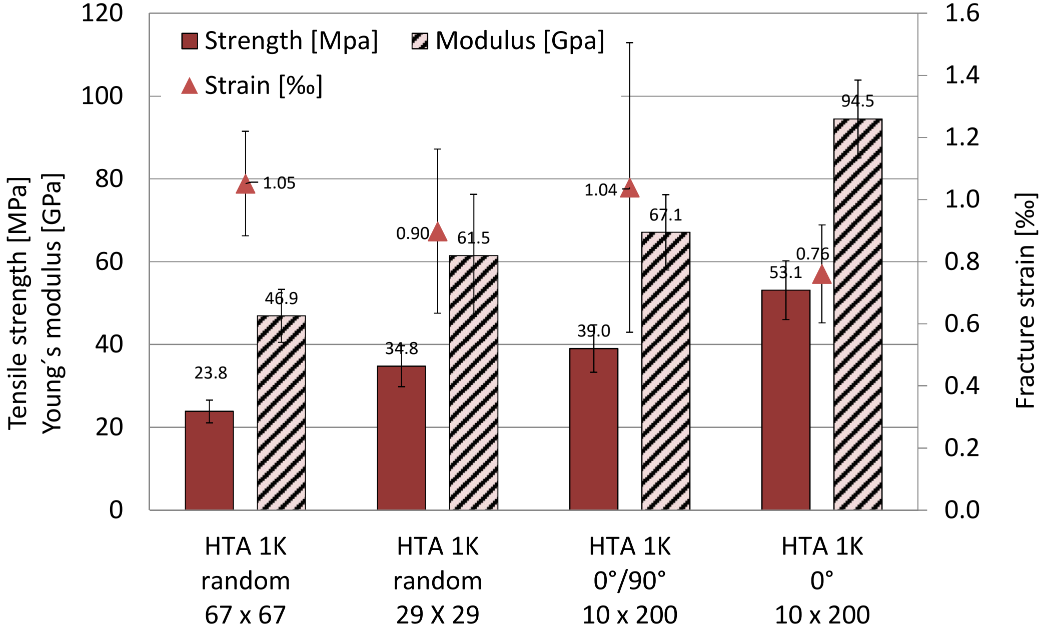




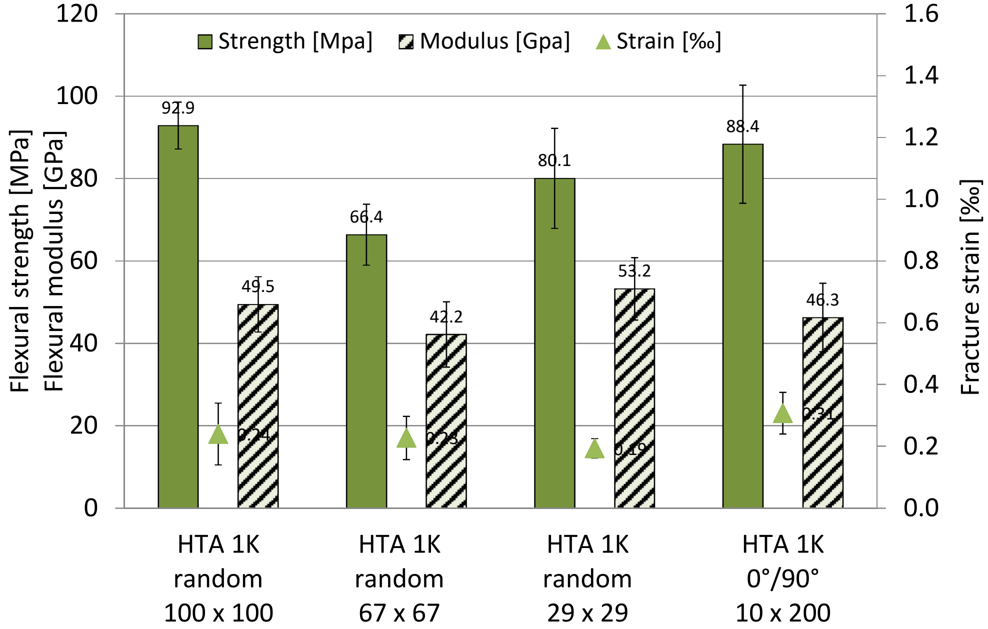
- 6 K fibers offer similar mechanical performance as 1K (67²).
- Fiber orientation leads to up to 2 x higher strength and modulus but lower fracture strain.

Influence of Loading Method

Tension



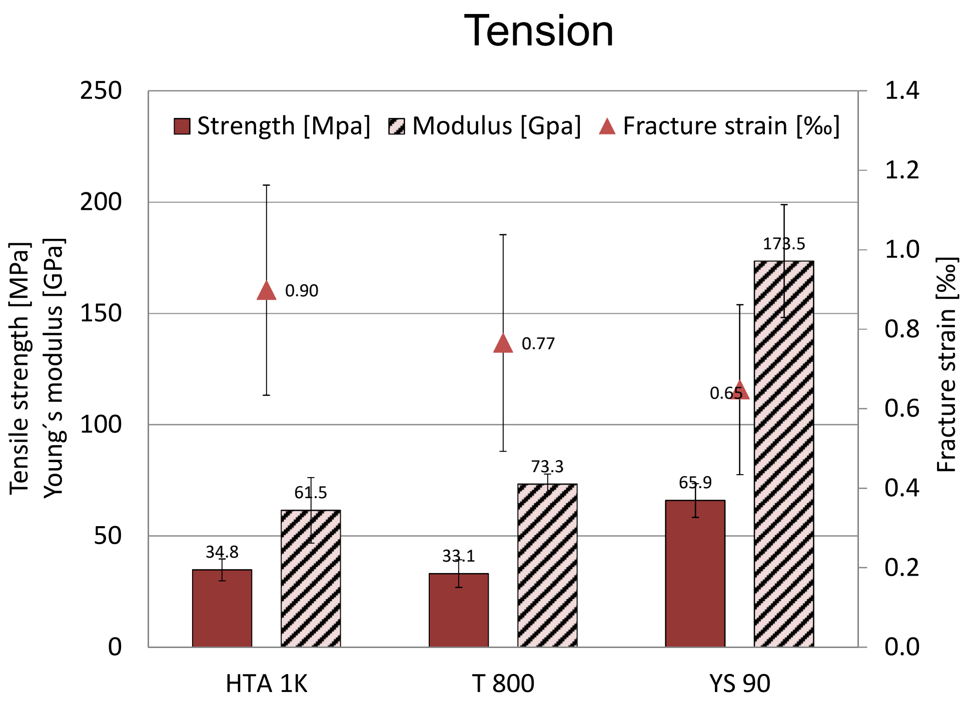
4-Pt. Bending

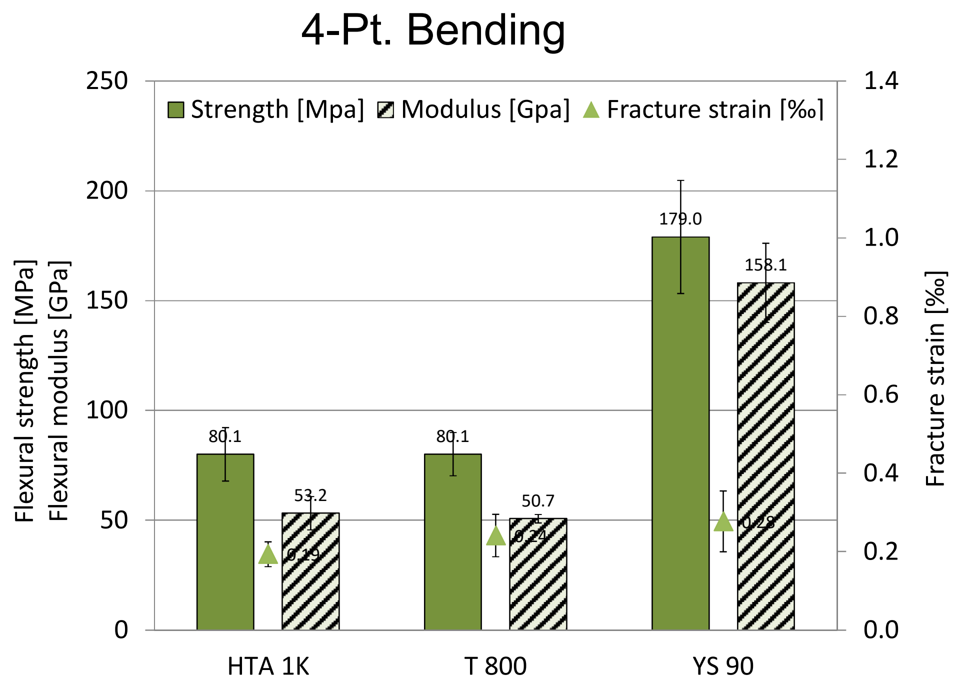


Tension:
- Overlap leads to higher strength (18 – 47 %) and modulus (13 – 30 %) for all fiber types.
- Highest strength and modulus for UD material (0°)

Bending:
- Lowest strength / modulus for multiple batches without overlap.
- Highest values for single batch and UD crossply (0°/90°).

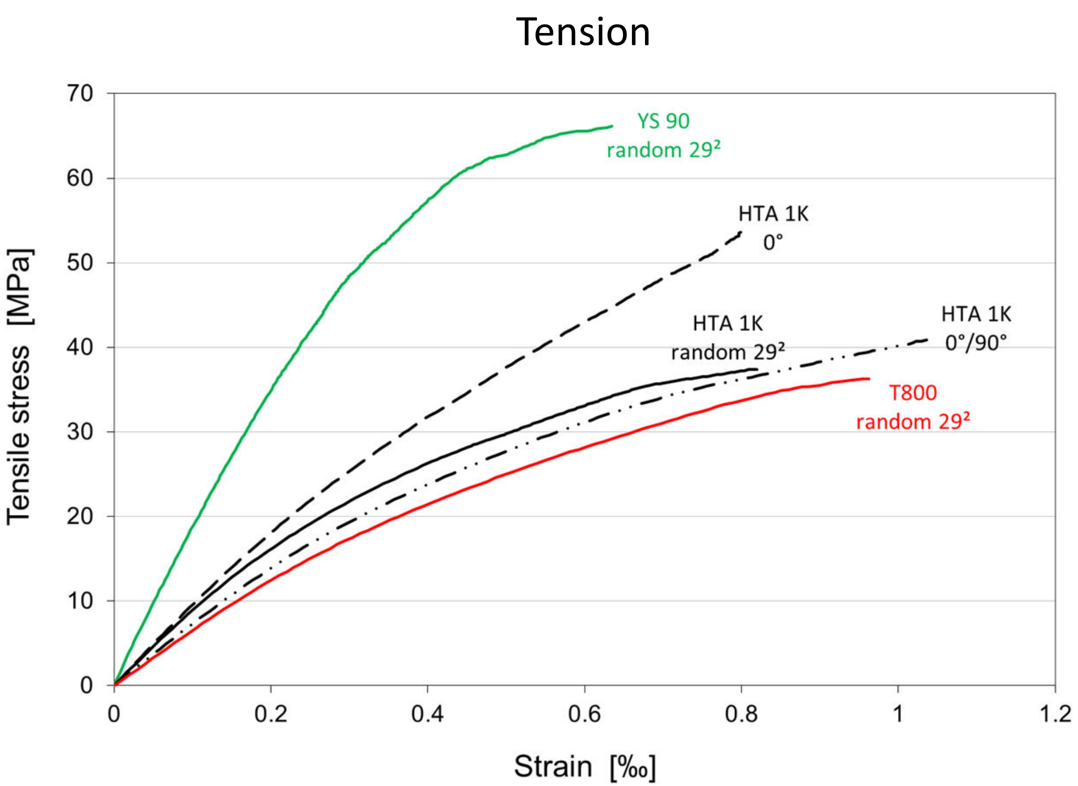
Influence of Fibre Type (29²)

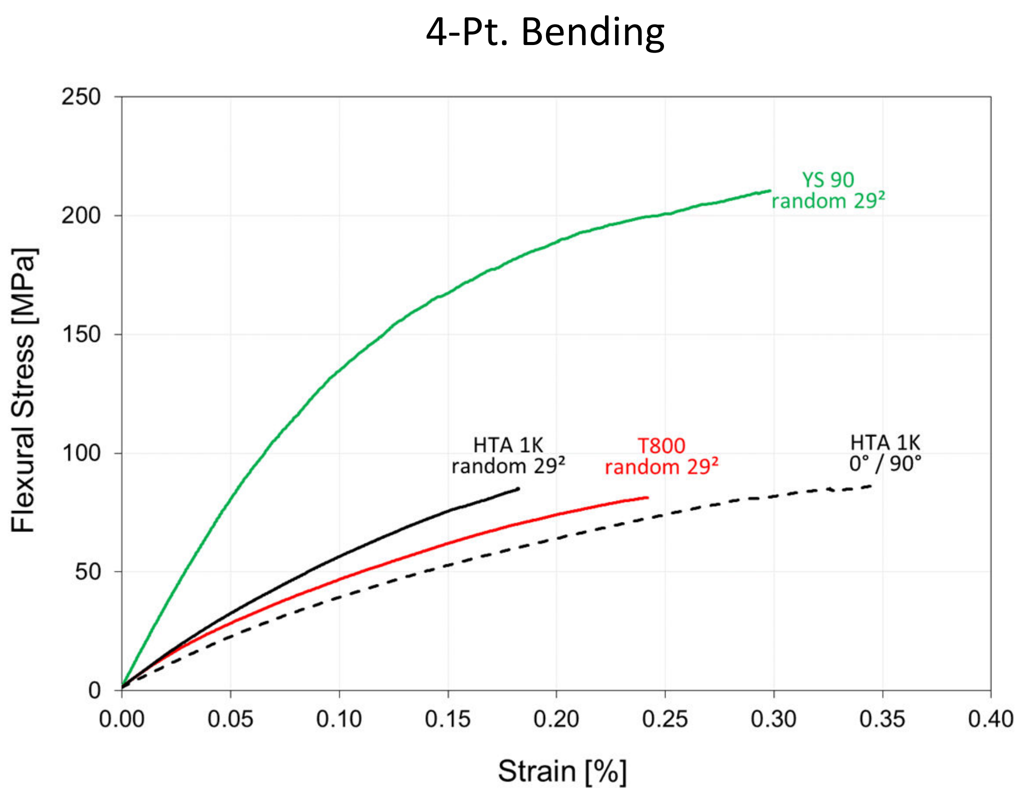




- T 800: no significant increase of mechanical performance, compared to HTA.
- YS 90: Increase of strength and modulus (89 – 300 %).
- Influence on fracture strain not clear.

Stress / Strain Behaviour (29 ²)





Conclusions

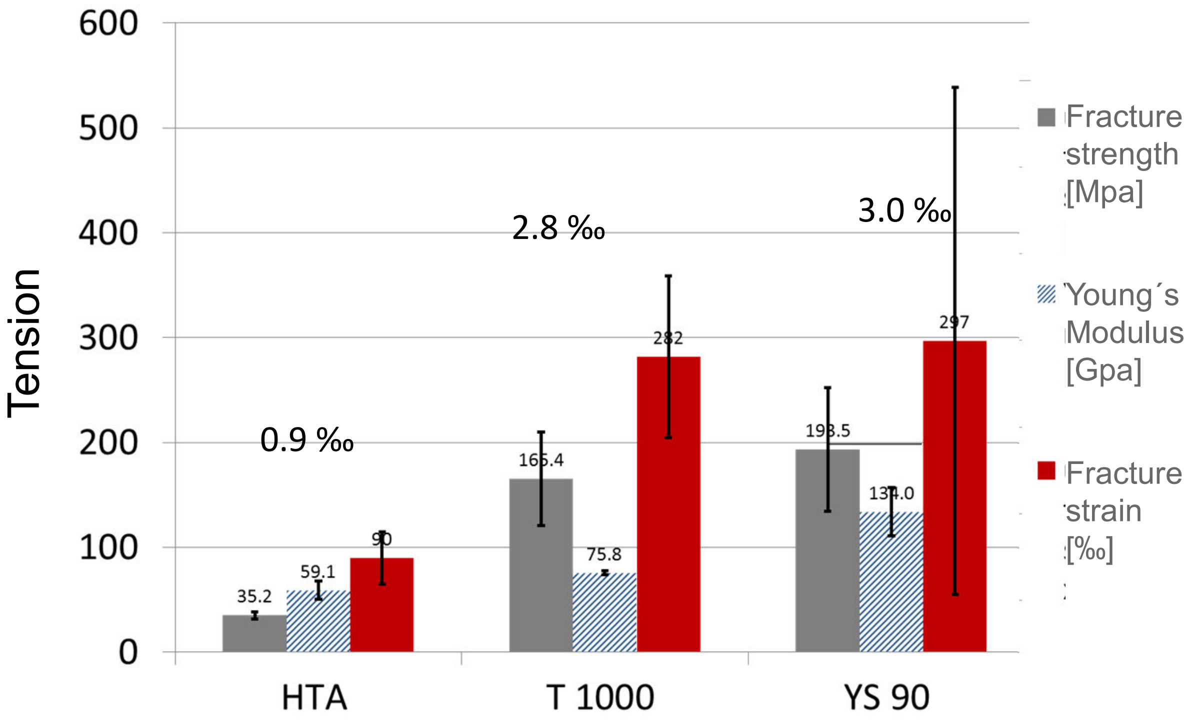
- Mechanical strength and modulus could be increased significantly (89 – 300 %) by using pitch based UHM fibers, instead of HTA and T800 fibers.
- T800 fibers showed no advantages compared to standard HTA fibers.
- 1K HTA showed no advantages compared to standard HTA 6K fibers, 1K advantageous for the near net shape manufacture of tiny parts.

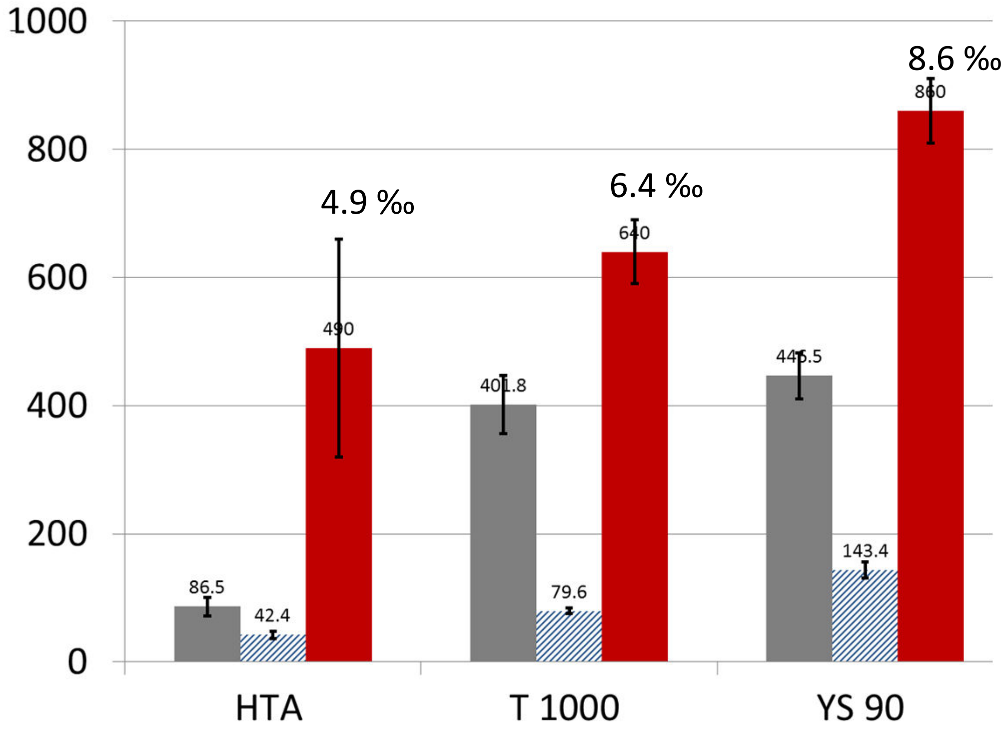
→ HTA (6K) for moderately loaded, YS 90 for high performance parts

- For small plates (100 x 100 mm²) single batch filling sufficient. For larger plates, multiple batch filling with overlapping cells is favourable.
- Mechanical properties can be influenced by fiber orientation (UD) → Strength and modulus can be tailored in highly loaded parts, manufactured in near net shape.

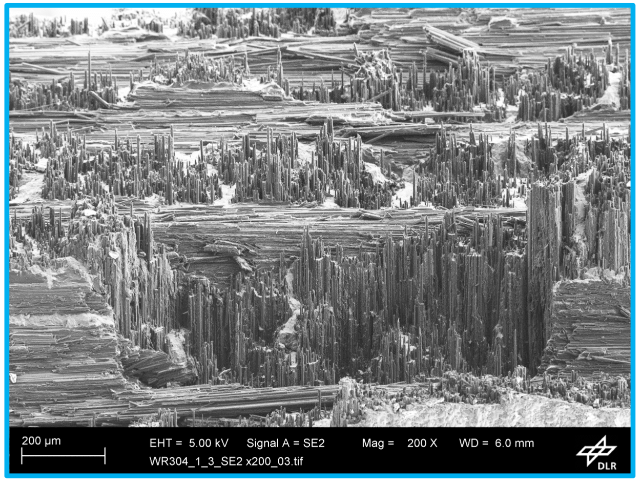
Thank You for Your Attention

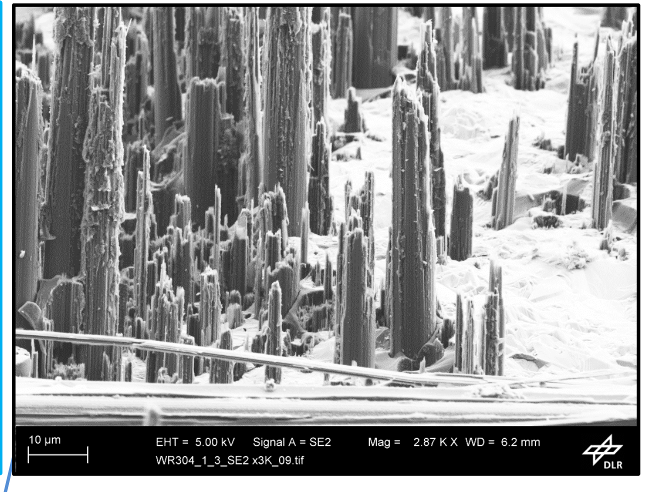
Results from C/C-SiC based on endless fiber and 0°/90° Crossply Laminate

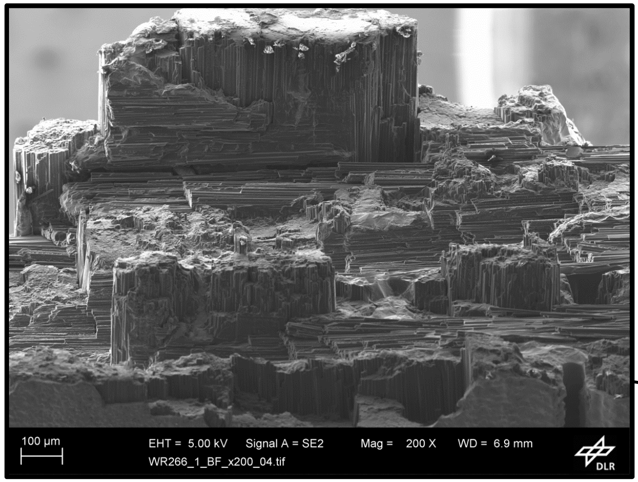


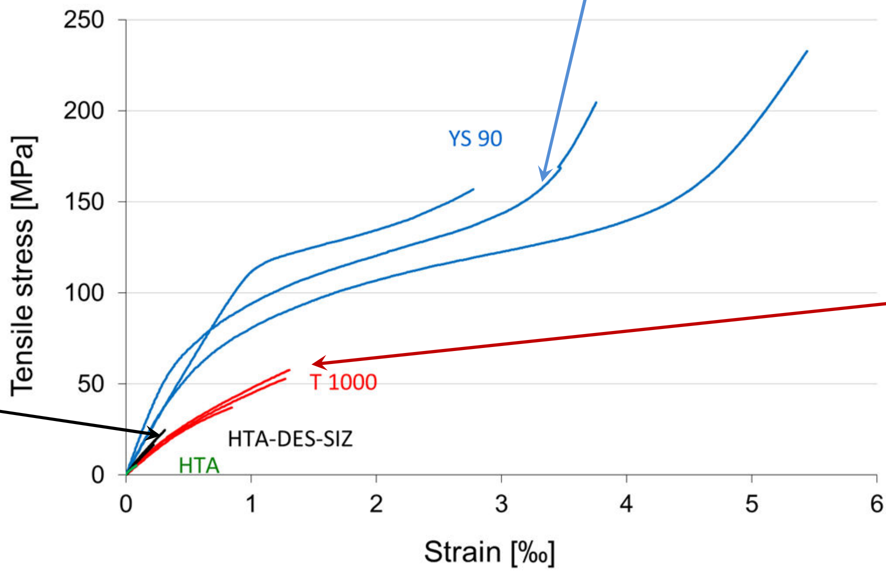


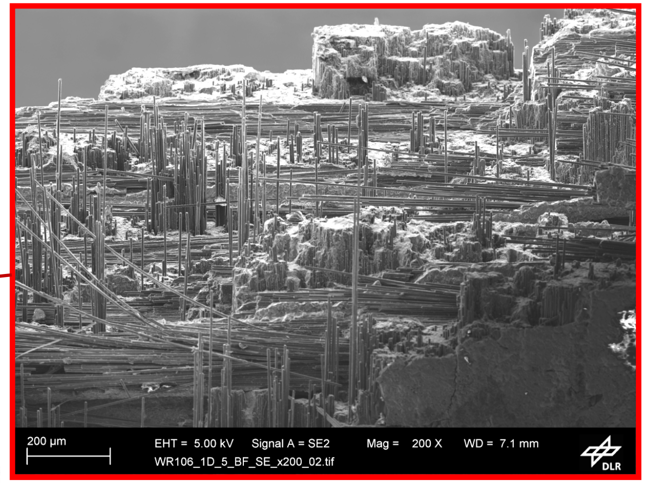
Fracture Behaviour





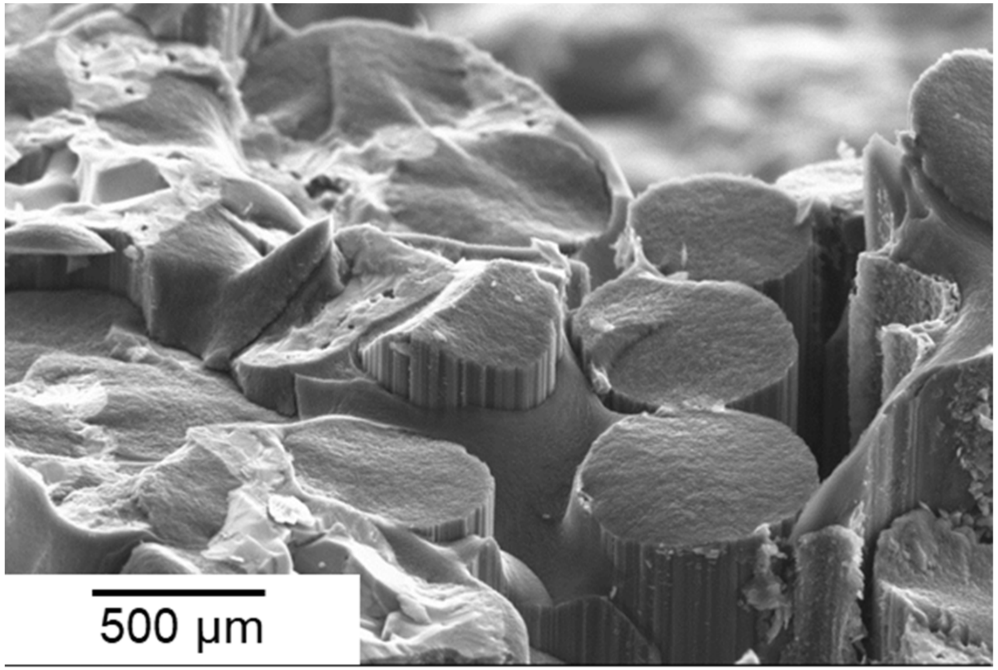






Fracture Behaviour

PAN based C-fiber



Pitch based C-fiber (UHM)