CMC with a Graded Lay-up Manufactured via LSI-Process

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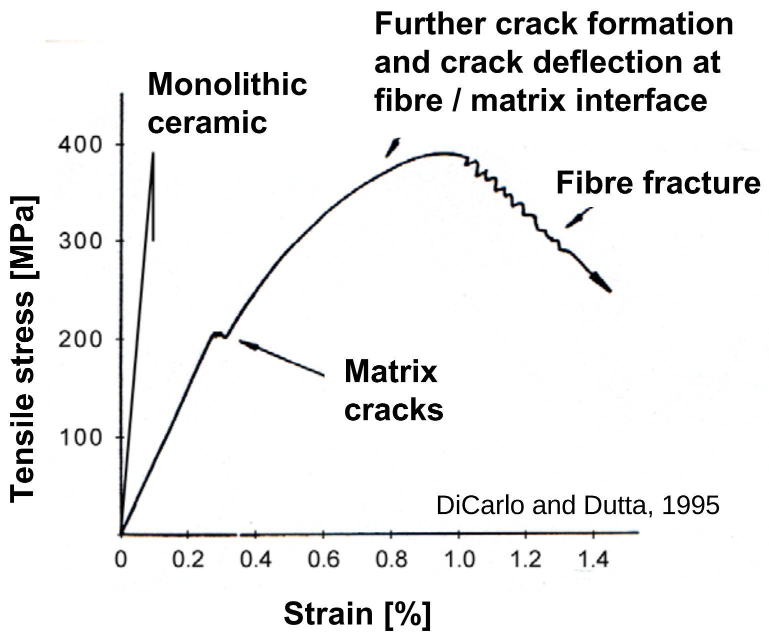
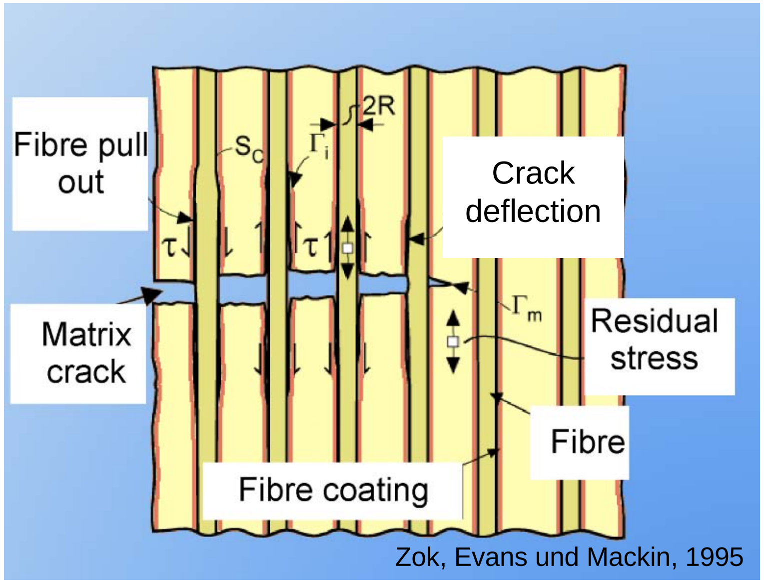
Ceramic Matrix Composites (CMC)

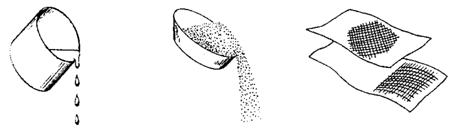




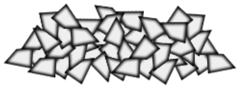
- Damage tolerant failure behaviour
  - Pseudo plasticity (crack deflection, fibre pull out)
  - Micro cracks, weak fibre matrix bonding
- Materials for lightweight structures
  - Low density (1.9 – 2.5 g/cm^3)
  - High specific material properties
- High temperature application
  - T > 1200 °C: C/SiC, C/C-SiC
  - T < 1200 °C: Ox/Ox, SiC/SiC
- New manufacturing methods
  - large sized, thin walled parts
  - Joining technologies

Liquid Silicon Infiltration Process (LSI)

Precursor Additives Fibres



Silicon-Granulate



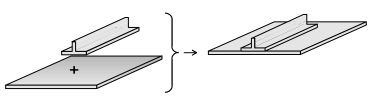
CFRP (SHAPING)
RTM-, Autoclave-, Filament-Winding-, Press-Technique
T < 250 °C

PYROLYSIS
Matrix Shrinkage
T > 900 °C
Inert Gas

SILICONIZATION
Si + C $\rightarrow$ SiC (Matrix)
T > 1420 °C
Vacuum

Intermediate Machining

Joining
Fixing C/C-Parts with Paste



In-process coating (SiCralee)

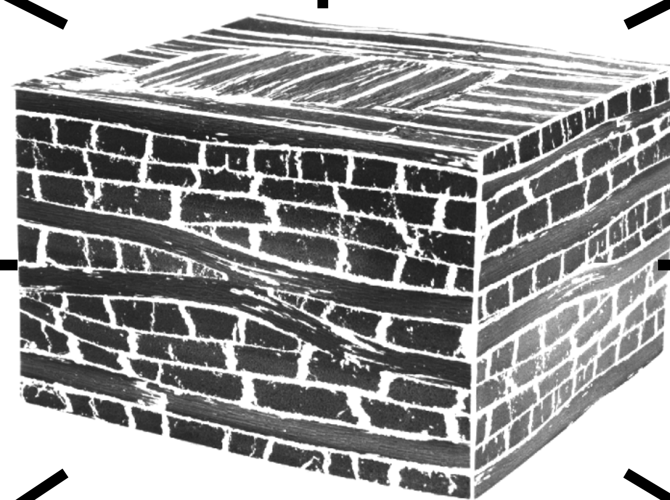
Finishing
Machining with Diamond Tools

General Properties of C/C-SiC Materials

High thermal shock stability

Damage tolerance

Internal oxidation protection



Good wear and corrosion resistance

Variable mass fractions of SiC and C

Low density (ca. 2 g/cm^3)

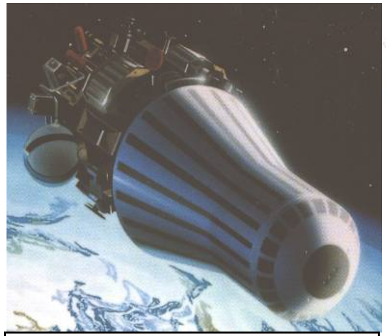
Low porosity

Short manufacturing times

C/C-SiC Thermal Protection Systems (TPS) for Reusable Spacecraft

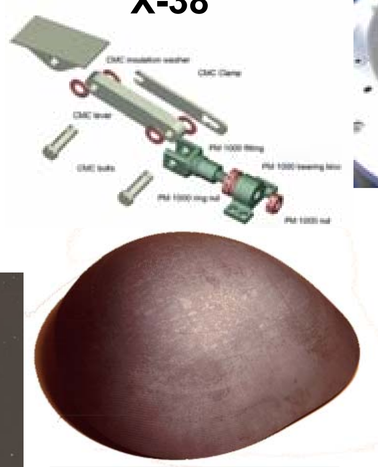
Material development

EXPRESS-CETEX



- Curved structure
- ∅ 300 mm, d=5 mm

X-38

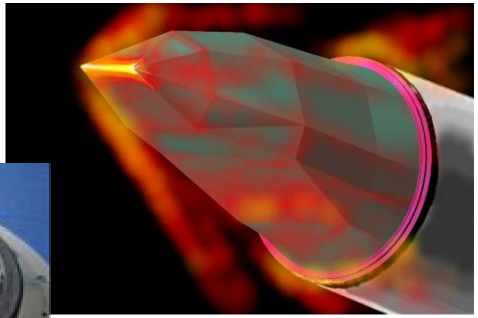


- Full scale nose cap for CRV of ISS
- ∅ 700 mm, h=190 mm, d=6 mm

Foton

- Segmented structure
- ∅ 300 mm, d =3 mm
- Re-entry flight 2005

Shefex

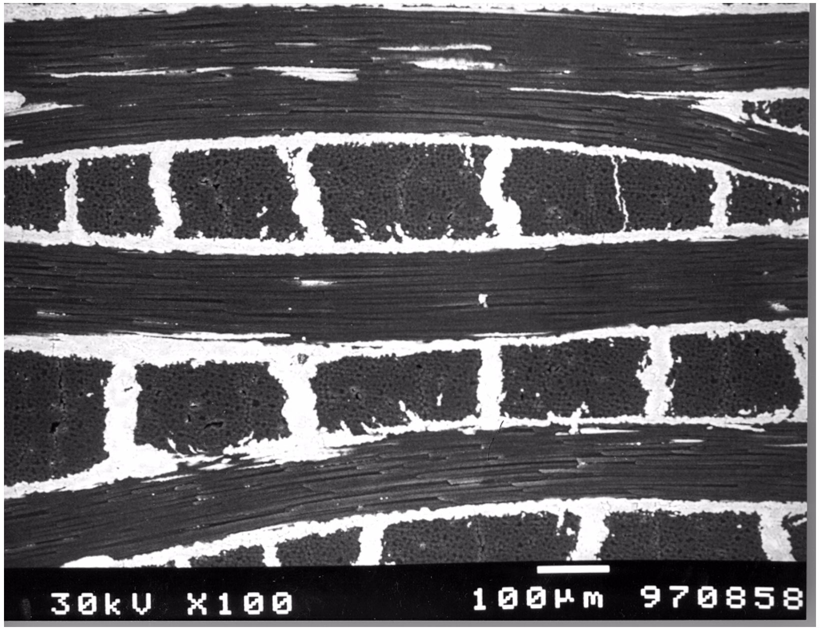


- Facetted structure
- ∅ 370 x 800 mm, d =3 mm
- T_{max}=2200 °C (Mach 7)
- High aerodynamic performance
- Low cost approach
- Flight test in 2005

1988 **2002** **2005**

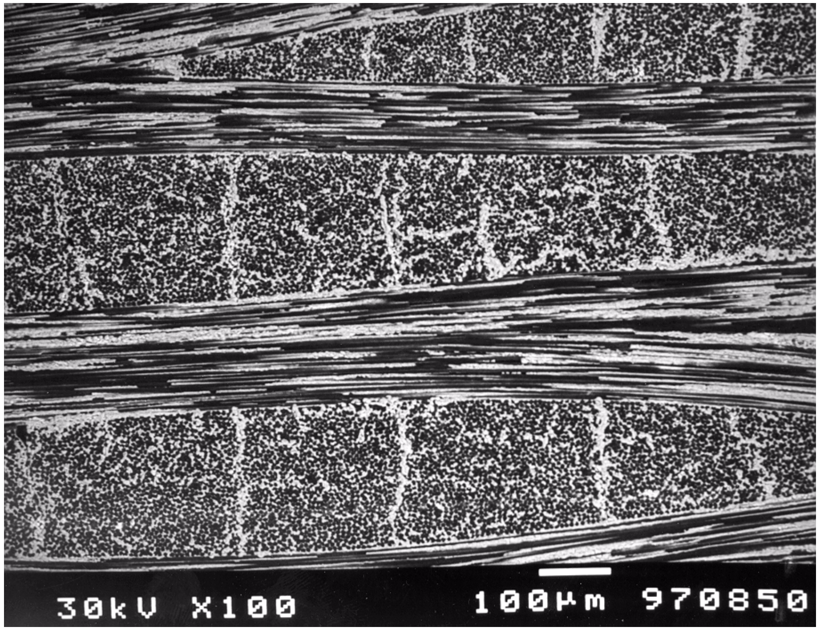
Tailor-design of C/C-SiC Microstructure and Properties

XB - Quality



Fibre bundle segmentation
High fibre content
High strength
Quasi-ductility

XD - Quality



Single fibre impregnation
High ceramic content
High stiffness
High abrasive resistance

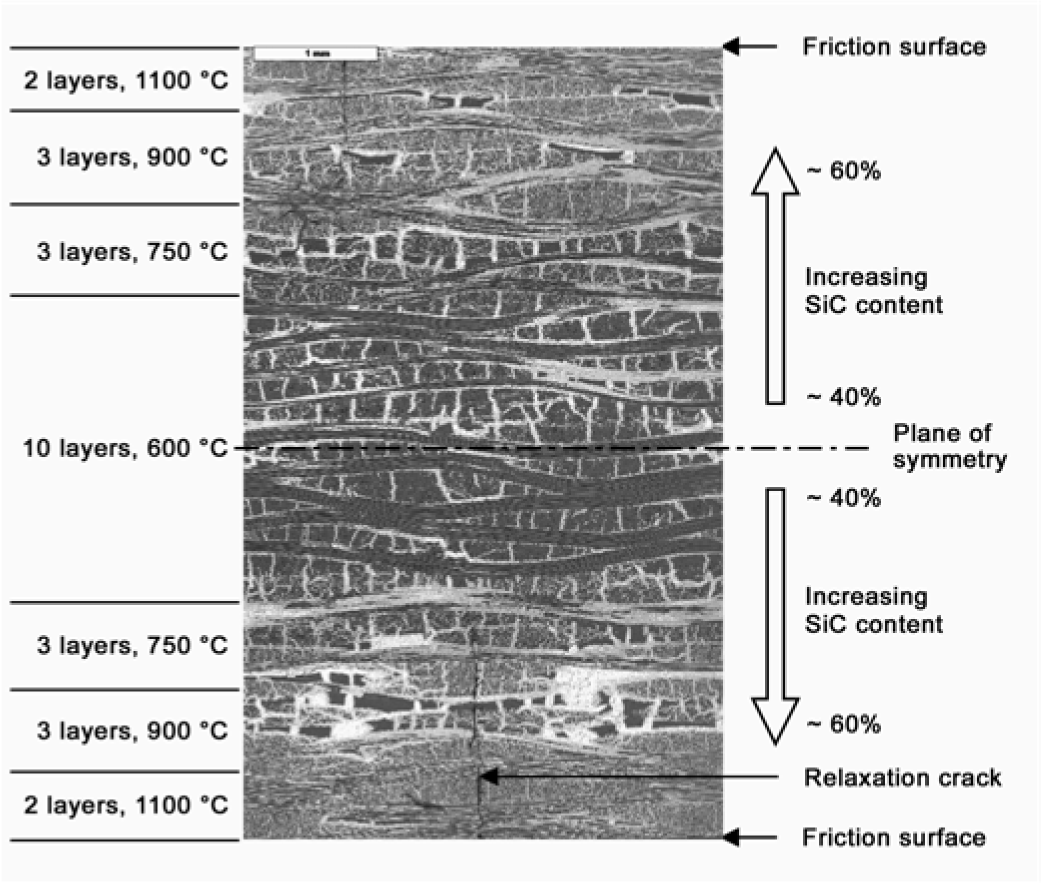
Control via raw materials and process parameters

Graded C/C-SiC Materials for Brake Pads

- **Symmetrical lay-up of fabrics**
- **Outer layers (XD) with**
  - **high SiC content (~ 60 vol.-%)**
  - **high density (ρ = 2.3 g/cm³)**
  - **low strength**
  - **fibres treated @ 1100 °C (N_2)**

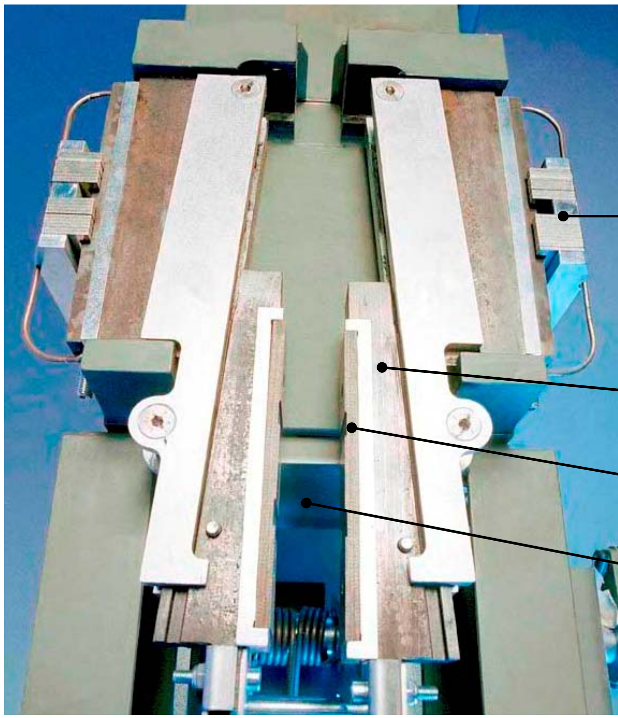
  ⇒ high wear resistance
- **Centre layers (XB) with**
  - **low SiC content (~ 40 vol.-%)**
  - **low density (ρ = 1.9 g/cm³)**
  - **low wear resistance**
  - **fibres treated @ 600 °C (N_2)**

  ⇒ high strength / thermal shock resistance.
- **Manufacture of CFRP preform via resin transfer moulding (RTM)**



Brake System and Brake Pads

Emergency brake for elevators (Schindler Elevator)



Brake calliper with U-shaped spring elements (steel plates)

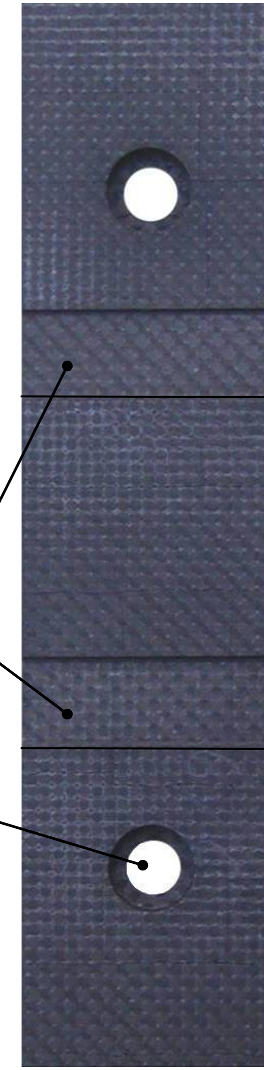
Bracket

Brake pad

Friction partner: Steel (St 44) guiding rail (not shown)

C/C-SiC brake pad (142 x 34 x 6 mm³; DLR)

- **2D-fabric reinforcement**
- **Machined out of plate (300 x 300 x 8 mm³)**



Grooves to collect wear particles

Countersink for screw joining in metallic bracket

Contact pressure very sensitive to brake pad thickness

⇒ No wear of brake pads and guiding rail required to ensure constant deceleration

Microstructure of Graded Brake Pads Based on Different Methods for CFRP Manufacture

RTM

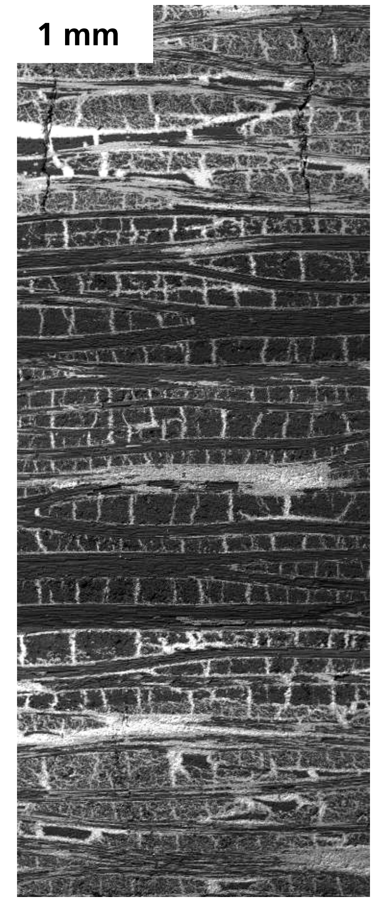
Warm pressing

8 layers (1100 °C)

18 layers (no thermal treatment)

8 layers (1100 °C)

Autoclave technique



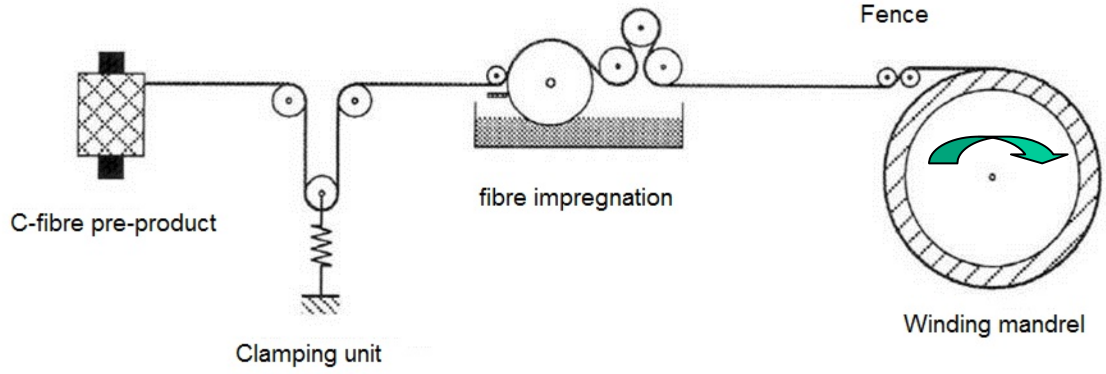
Material Properties of Brake Pads Based on Different CFRP Manufacture Methods

Manufacture method		RTM	Autoclave	Warm Pressing
$\sigma_{b,\ max.}$	[MPa]*	64.7	100.8	100.4
ρ	[g/cm³]	2.21	2.03	2.08
e'	[%]	< 5	2.06	1.28

* 3 point bending tests; sample geometry 25 x 10 x 6 mm³

- **Reduced XD layers in autoclave and warm pressed materials lead to 50 % increase in bending strength.**
- **First tribological investigations in elevator test facility showed comparable of wear behaviour and coefficient of friction.**

Preform Manufacture - Wet Filament Winding



Warm Pressing for manufacture of plate material

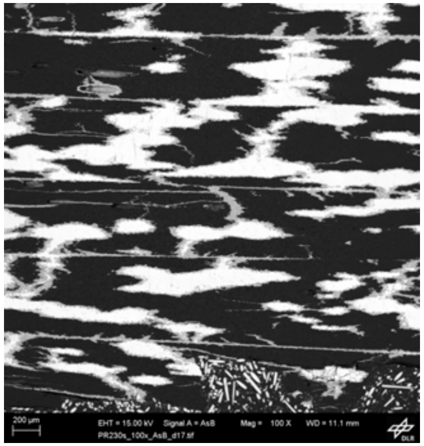
Pressure less curing on mandrel in oven for manufacture of tubes

Raw materials and equipment:

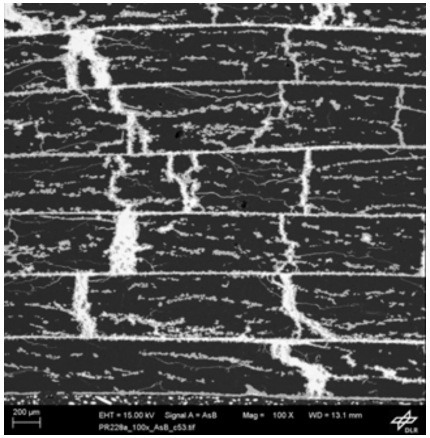
- C-fibre T800 12K
- Precursor JK 60 (phenolic resin)
- Filament winding machine controlling winding speed and angle
- Aluminium mandrel equipped with Teflon tape
- IR-lamp and ventilation for support of evaporation of solvent

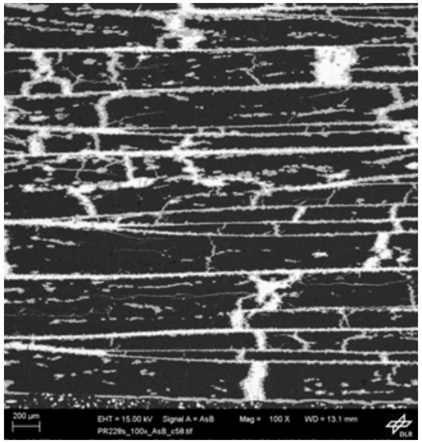
SEM micrographs of filament wound C/C-SiC tubes (I): view in axial (top) and tangential direction (bottom)

Winding angle 15°

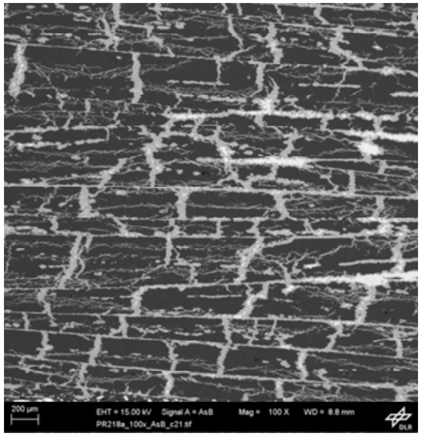


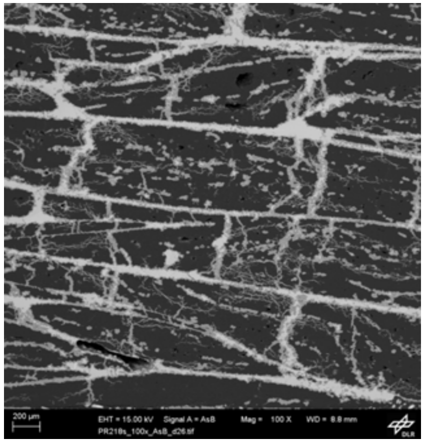
Winding angle 30°



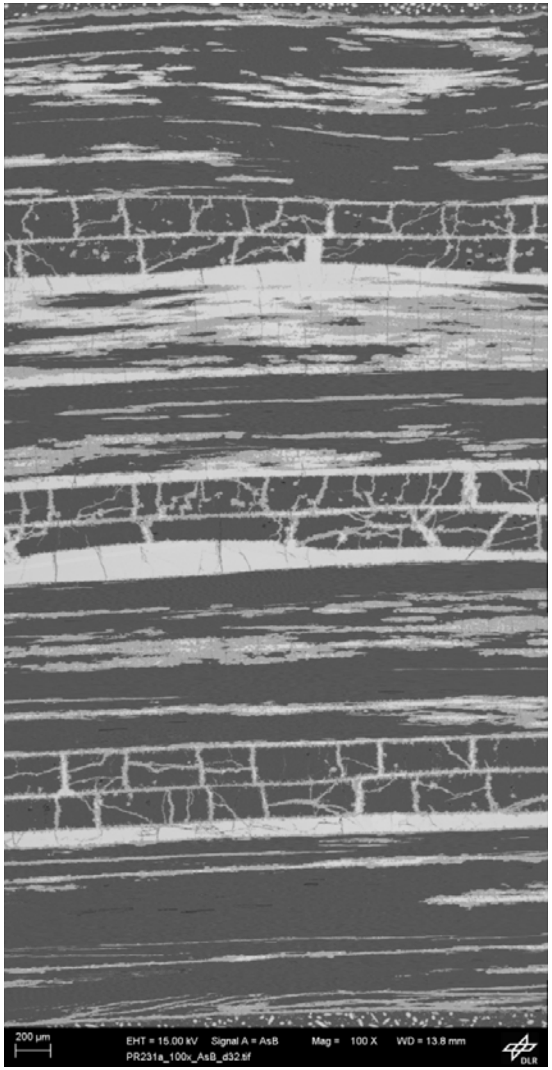


Winding angle 45°





SEM micrographs of filament wound C/C-SiC tubes (II): view in axial (top) and tangential direction (bottom)



90°

+/-15°
delamination

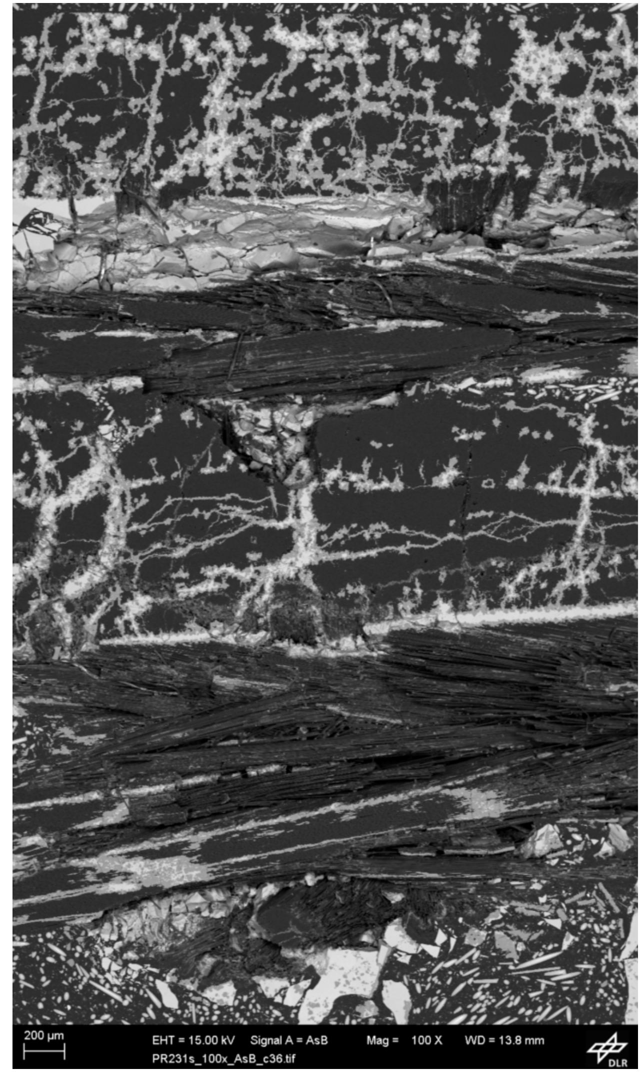
90°

+/-15°
delamination

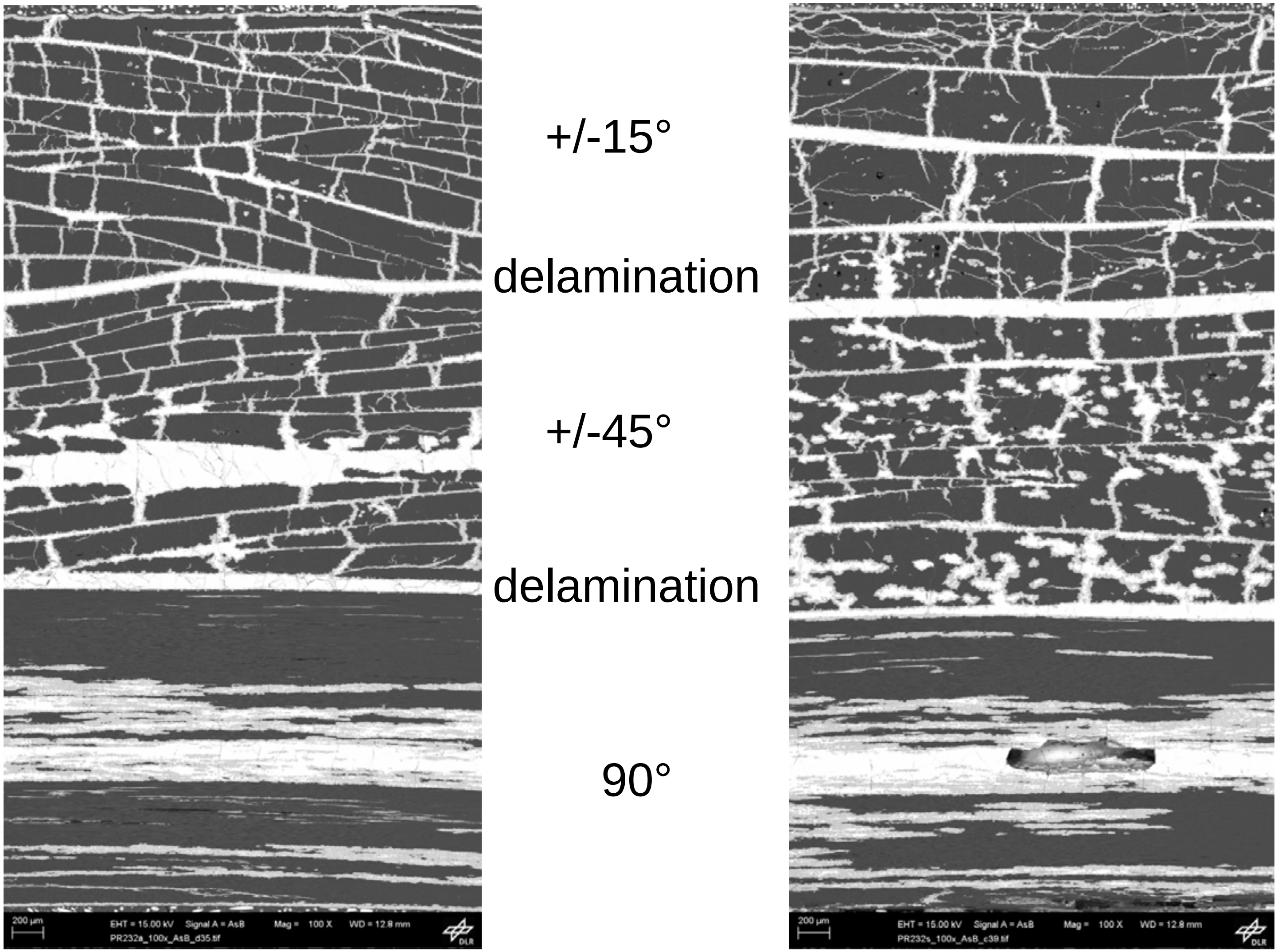
90°

+/-15°
delamination

90°



SEM micrographs of filament wound C/C-SiC tubes (III): view in axial (le.) and tangential direction (ri.)



SEM micrographs of filament wound C/C-SiC tubes (IV): view in axial (le.) and tangential direction (ri.)

+/-30°

+/-30°

+/-30°

+/-60°

+/-30°

+/-60°

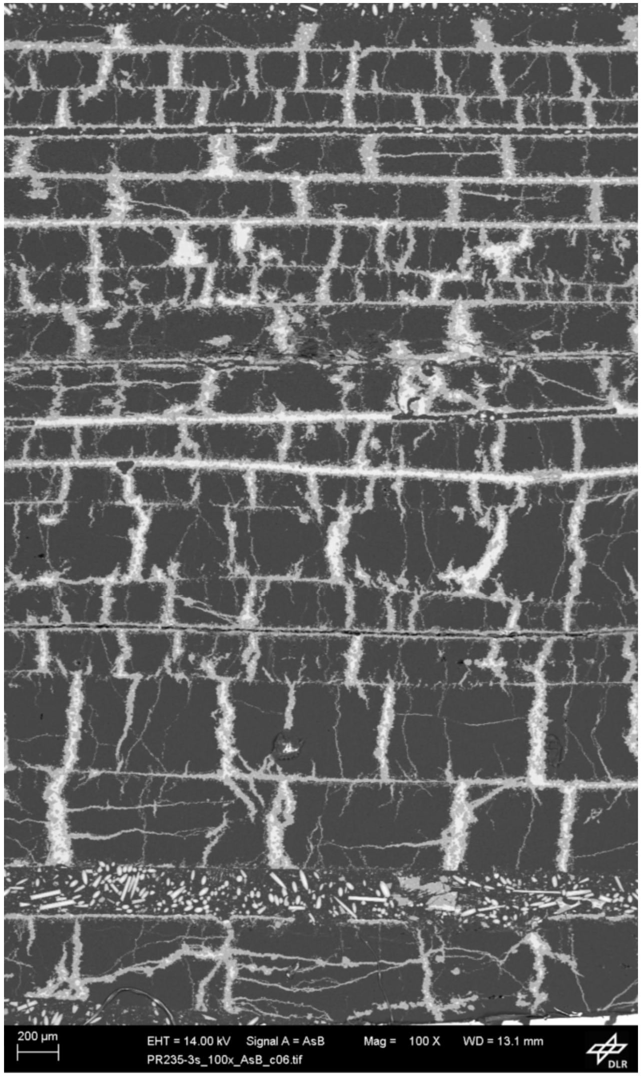
90°

+/-60°

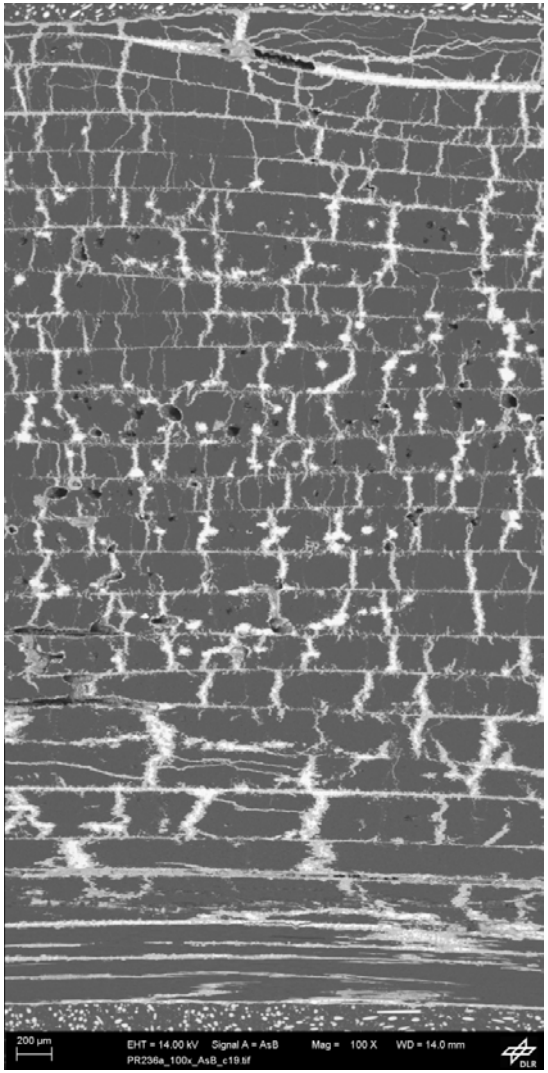
90°

+/-60°

90°



SEM micrographs of filament wound C/C-SiC tubes (V): view in axial (le.) and tangential direction (ri.)



cross ply

+/-15°

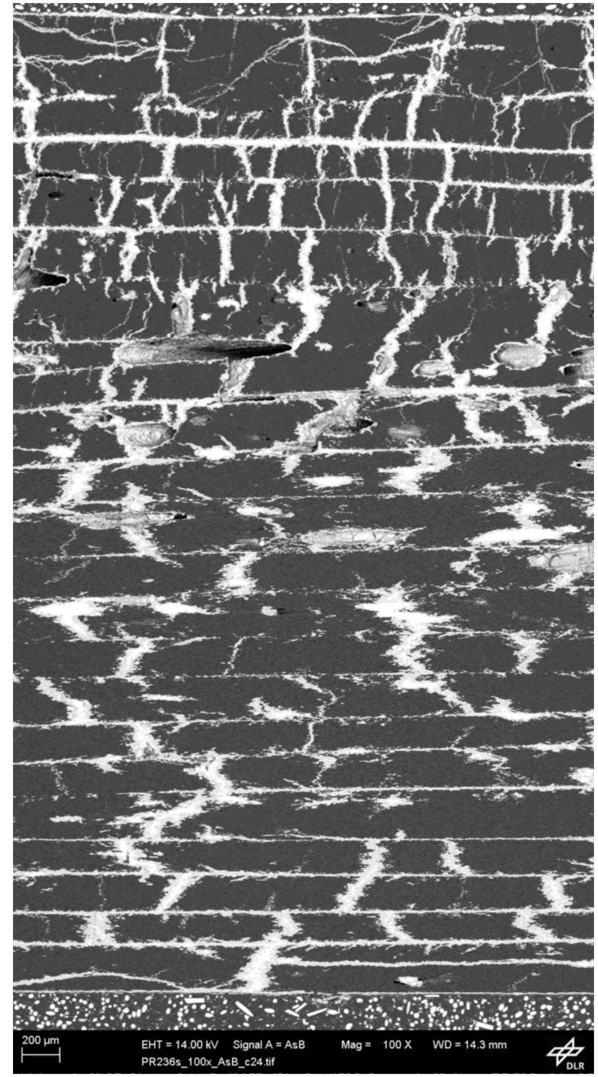
+/-30°

+/-45°

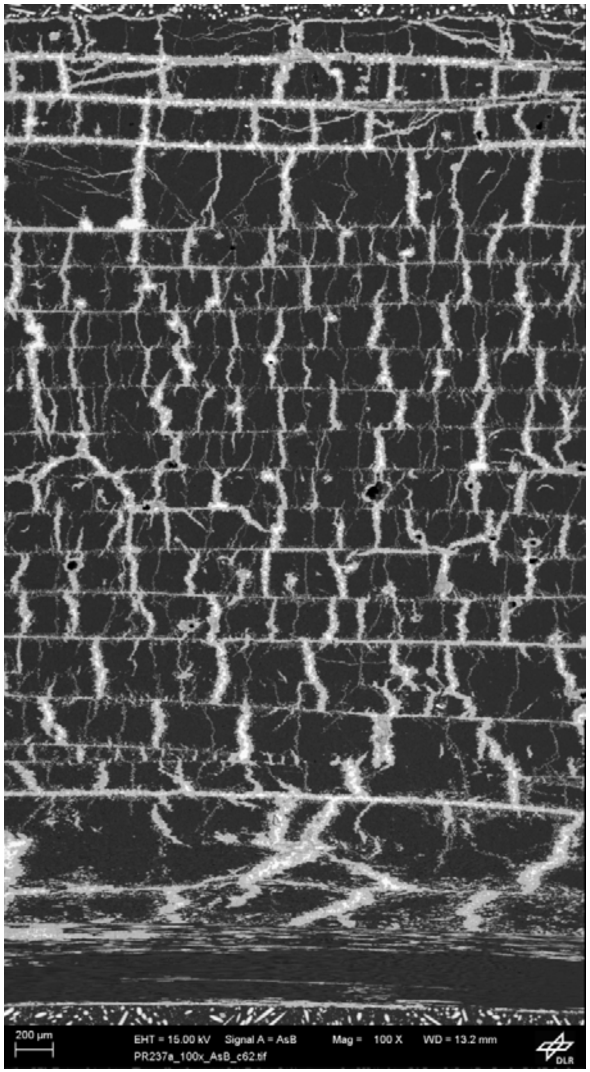
+/-60°

+/-75°

90°



SEM micrographs of filament wound C/C-SiC tubes (VI): view in axial (le.) and tangential direction (ri.)



cross wound

+/-15°

+/-30°

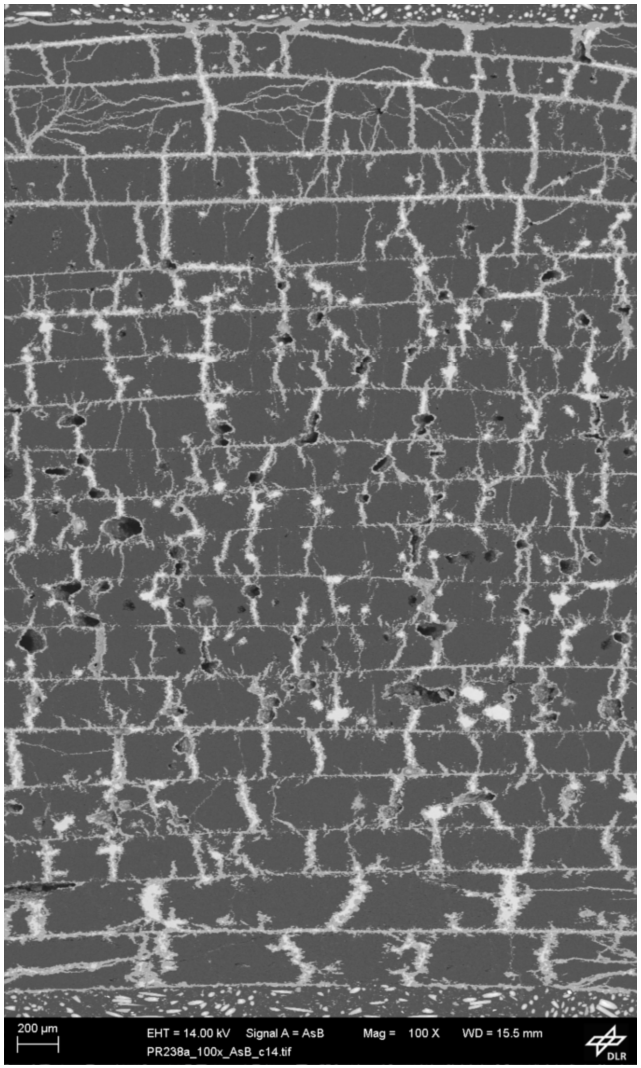
+/-45°

+/-60°

+/-75°

90°

SEM micrographs of filament wound C/C-SiC tubes (VII): view in axial (le.) and tangential direction (ri.)



cross ply

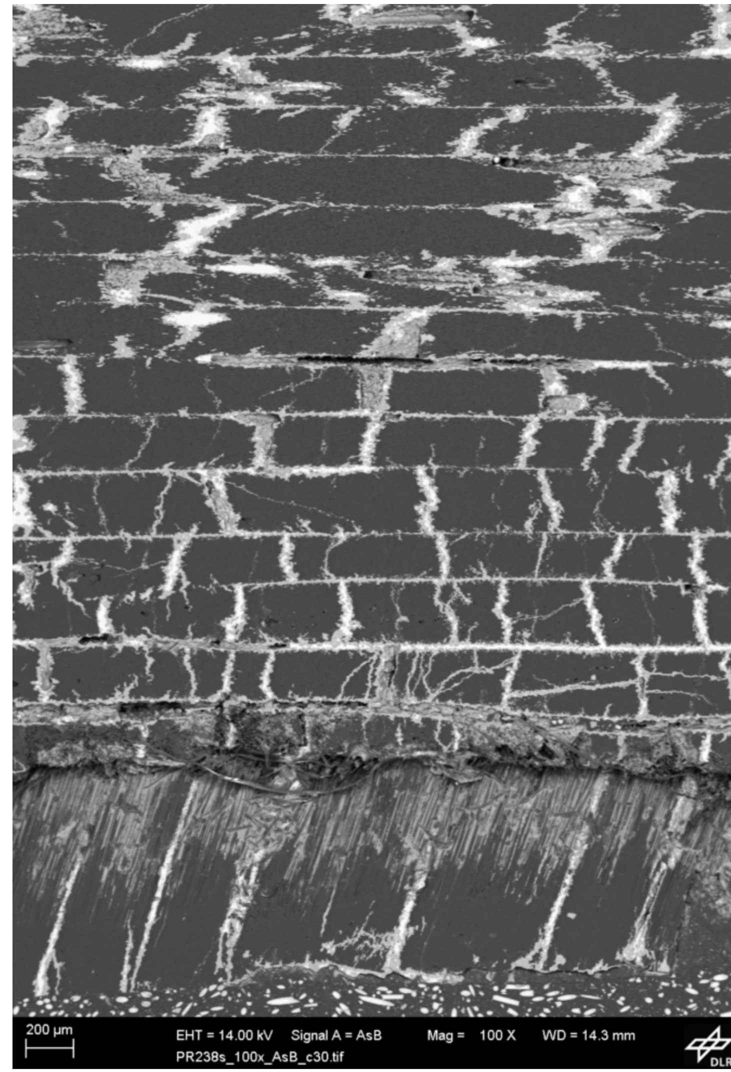
+/-15°

+/-30°

+/-45°

+/-60°

+/-75°



Summary

- The cost efficient LSI-process opened up new application areas besides aerospace
- C/C-SiC materials can be tailor-designed w.r.t. micro structure and SiC content, and therefore provide excellent properties
- C/C-SiC materials based on graded microstructures have been successfully developed for brake pads in emergency brakes of high speed elevators
- CFRP manufacture based on autoclave technique and warm pressing provides high potential for cost reduction
- Filament winding of C-fibres was successfully applied to improve mechanical properties similar to CFRP
- Winding angles strongly influence process parameters such as shrinkage during curing and pyrolysis
- Combining suitable winding angles open up new possibilities to tailor-design properties of C/C-SiC such as mechanical strength