CMC Materials for Aircraft Brakes

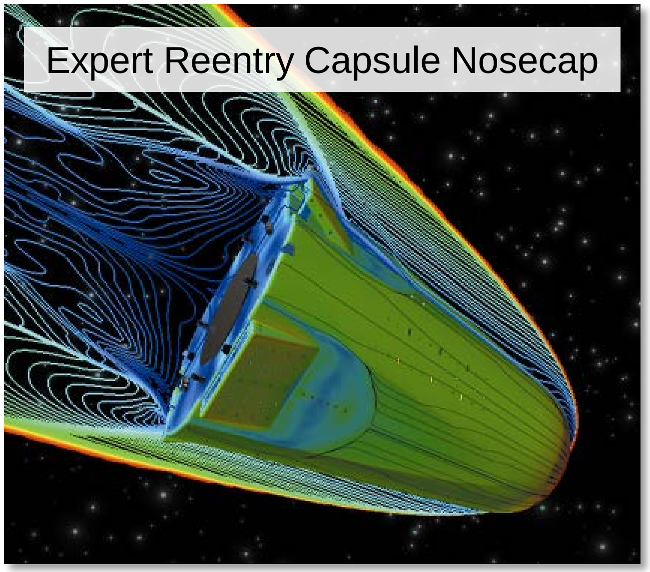
Bernhard Heidenreich, Linda Klopsch, Dietmar Koch

DLR– German Aerospace Center,
Institute of Structures and Design, Stuttgart, Germany

11th International Carbon Festival
2nd Global Carbon Cluster Forum

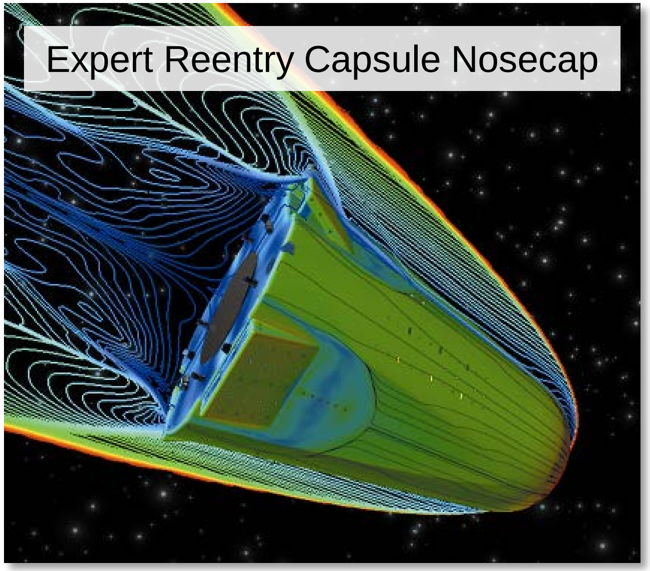
October 5-7, 2016
Jeonju, Korea

C/C-SiC Materials - From Space to Brakes

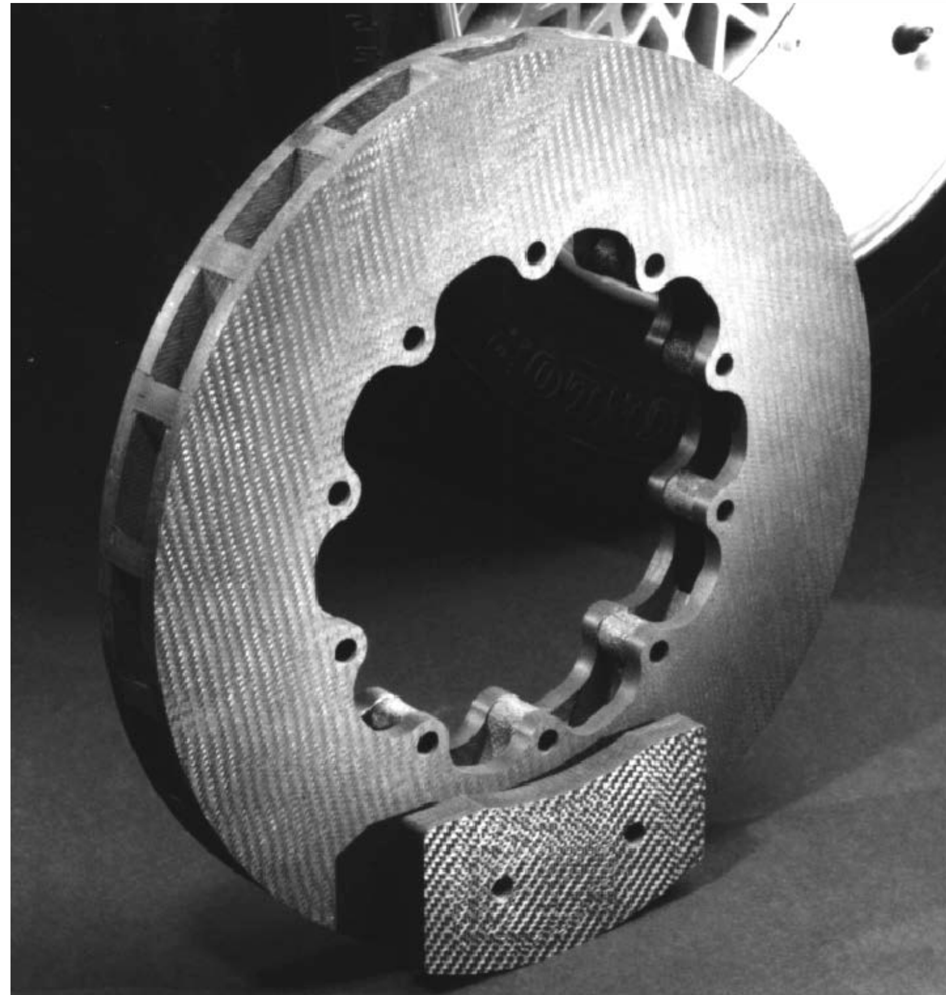


- High temperature stability (thermal shock, hot spots)
- High abrasion resistance

C/C-SiC Materials - From Space to Brakes



Know how in processing and design of hard and high temperature stable materials and parts



Why Ceramic Brake Systems are Attractive

Performance

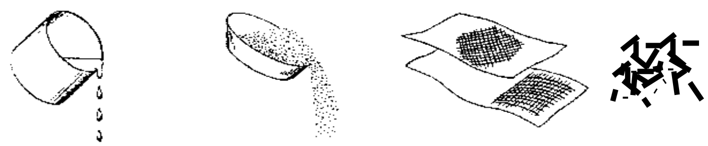
Costs

- Reduced weight
  20 – 25 kg per car
  Density: 2 g/cm³ (cast iron: 7 g/cm³)
- High hardness, low wear rates
- Improved performance and comfort (short braking distance, no judder, no fading)
- Corrosion resistance, low dust pruduction
- Advanced braking systems for heavy and fast cars, escalators, trains, planes

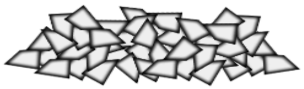
DLR

Manufacturing Process: Liquid Silicon Infiltration

Precursor | Additives | Fibers



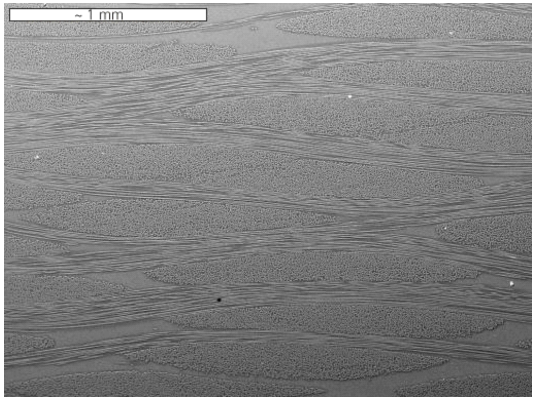
Silicon Granules



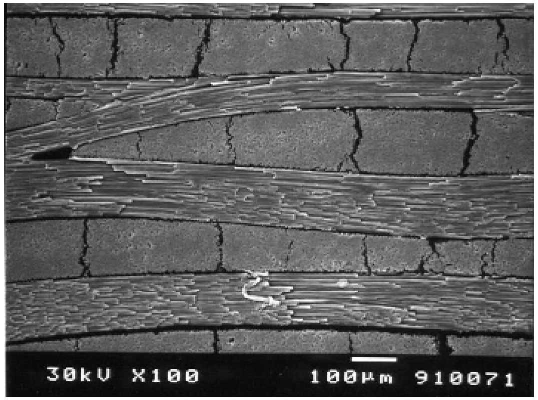
CFRP (Shaping)
$T < 250$ ºC

Pyrolysis
$T > 900$ ºC

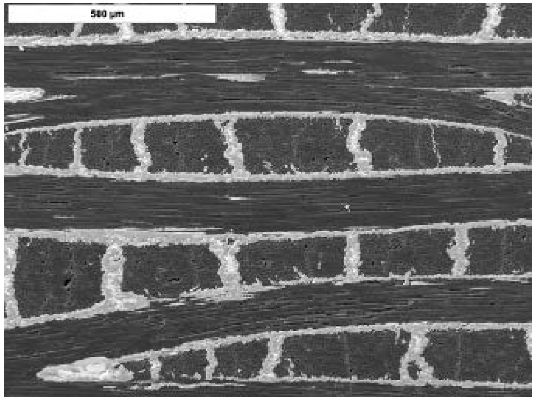
Siliconization
$Si + C \rightarrow SiC$
$T > 1500$ ºC



CFRP



C/C



C/C-SiC

Effect of Fiber Reinforcement in Ceramics

brittle vs. non catastrophic

Tailorable Material Properties

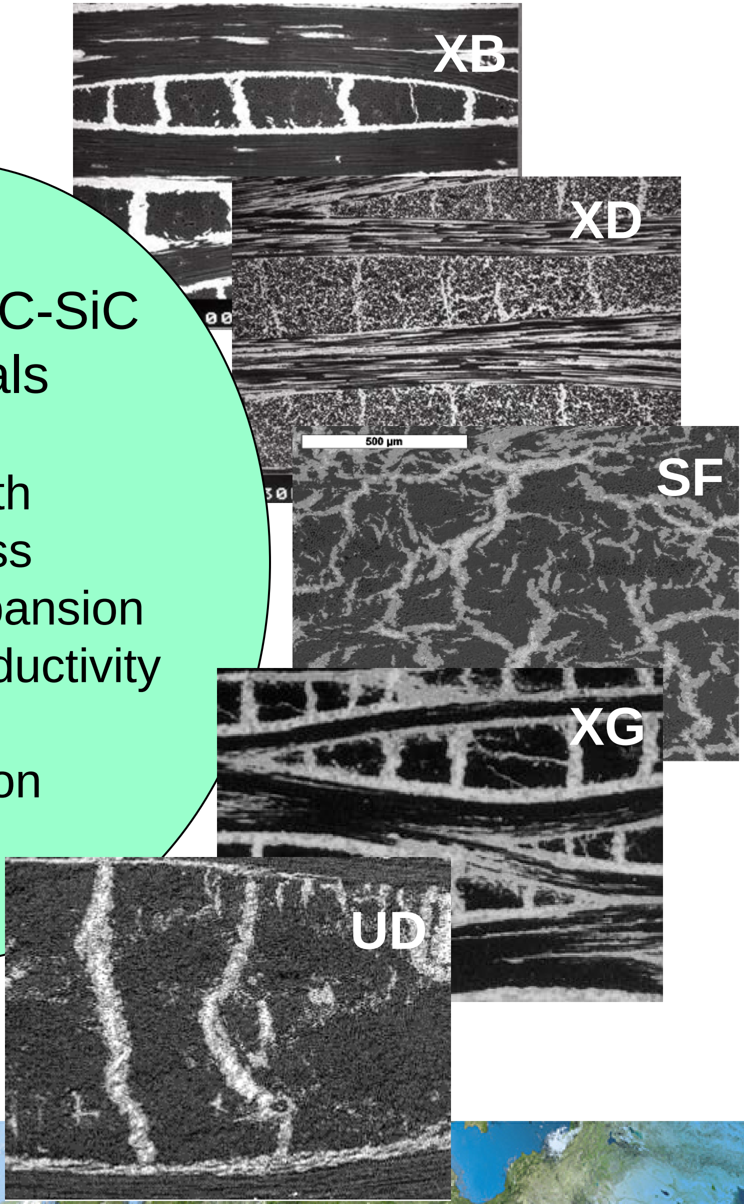
Variation parameter

Raw Materials
- Fibre type
- Fibre preform
- Fibre orientation
- Precursor
- Additives
- Si type

Processes
- Fibre pretreatment
- Process times
- Graphitizing
- Coatings

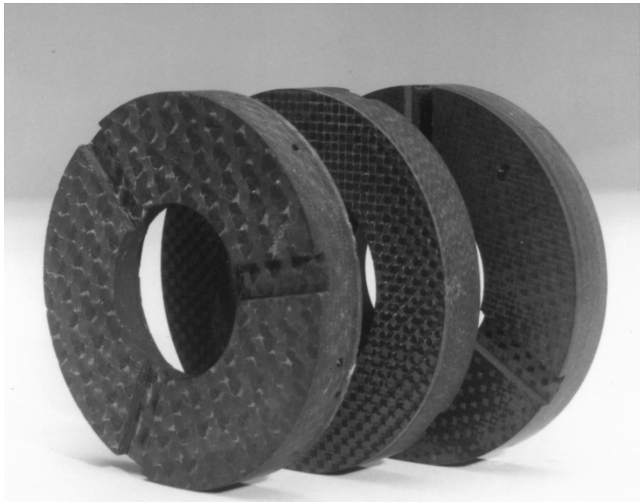
Tailored C/C-SiC Materials

Strength
Stiffness
Thermal expansion
Thermal conductivity
Wear
Oxidation
Cost



DLR

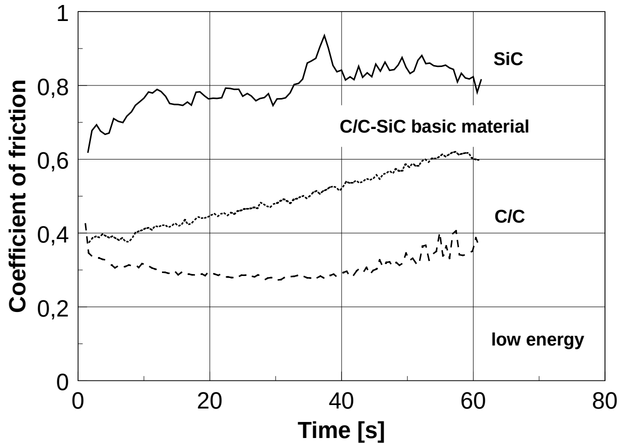
Tribological Properties of C/C-SiC Materials



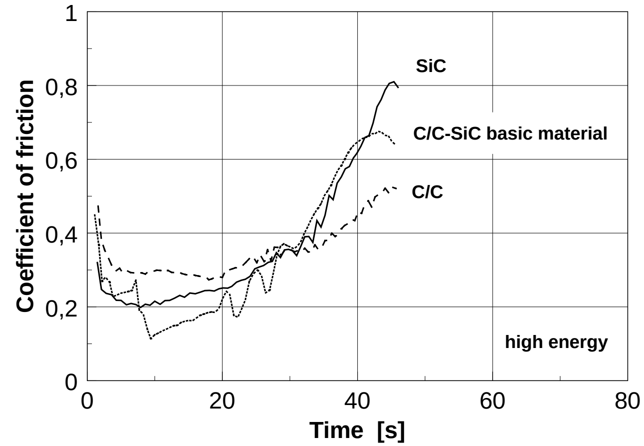
Friction samples
Ø 70 mm

Variation of:

- SiC, C, Si content
- Fibre type
- Fibre architecture
- …

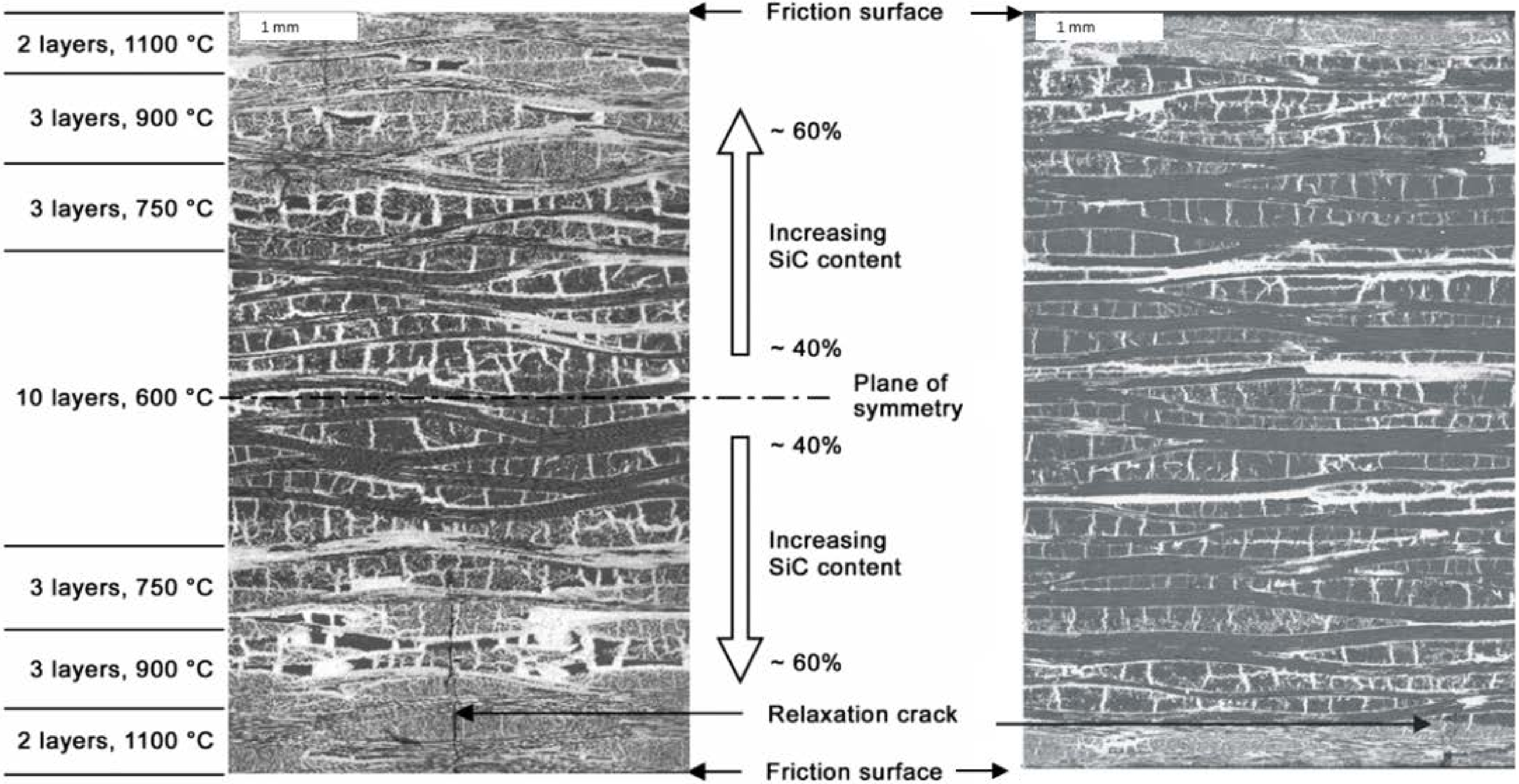


Low Energy Braking
(0.1 MPa; 6 m/s → 0.3 W/mm²; 20 kJ)



High Energy Braking
(0.35 MPa; 16 m/s, →3 W/mm²; 80 kJ)

Graded C/C-SiC With SiC Rich Friction Surface

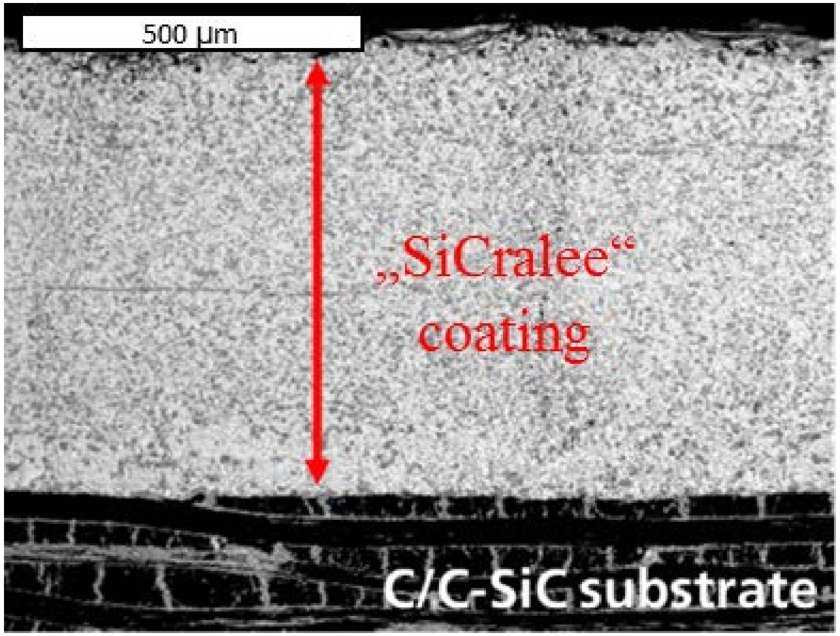


RTM

Autoclave

Frieß et al., Adv.Sci.Tech., 2003

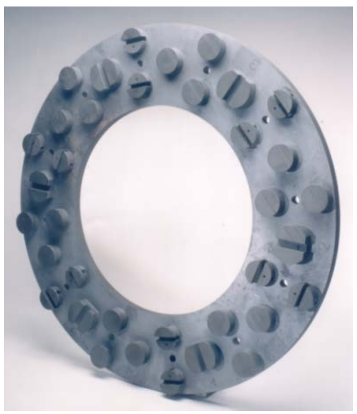
SiCralee Coating



- thick and stable SiCralee coating on segmented brake disc (≈ 290 x 100 x 12 mm³)
- after high performance testing no spallation visible
- deposition of sintermetallic brake pad material

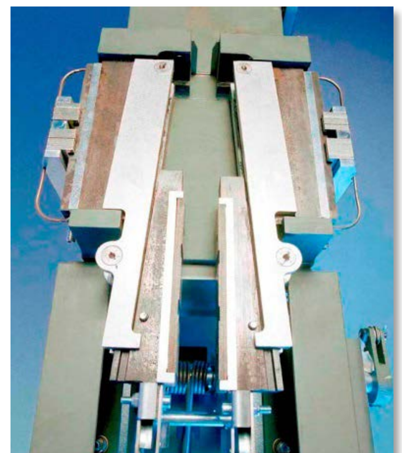
Brake Development at DLR

Basic research (from 1990) → Commercial car brakes (2001) → Other friction application (2004) → Propeller brake (2012)



ICE brake (Matech-project)

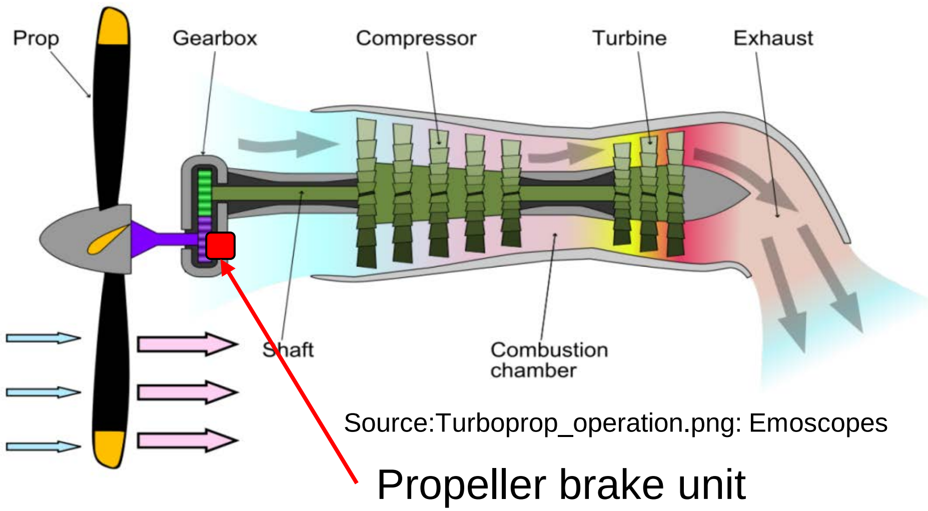
Porsche / SGL



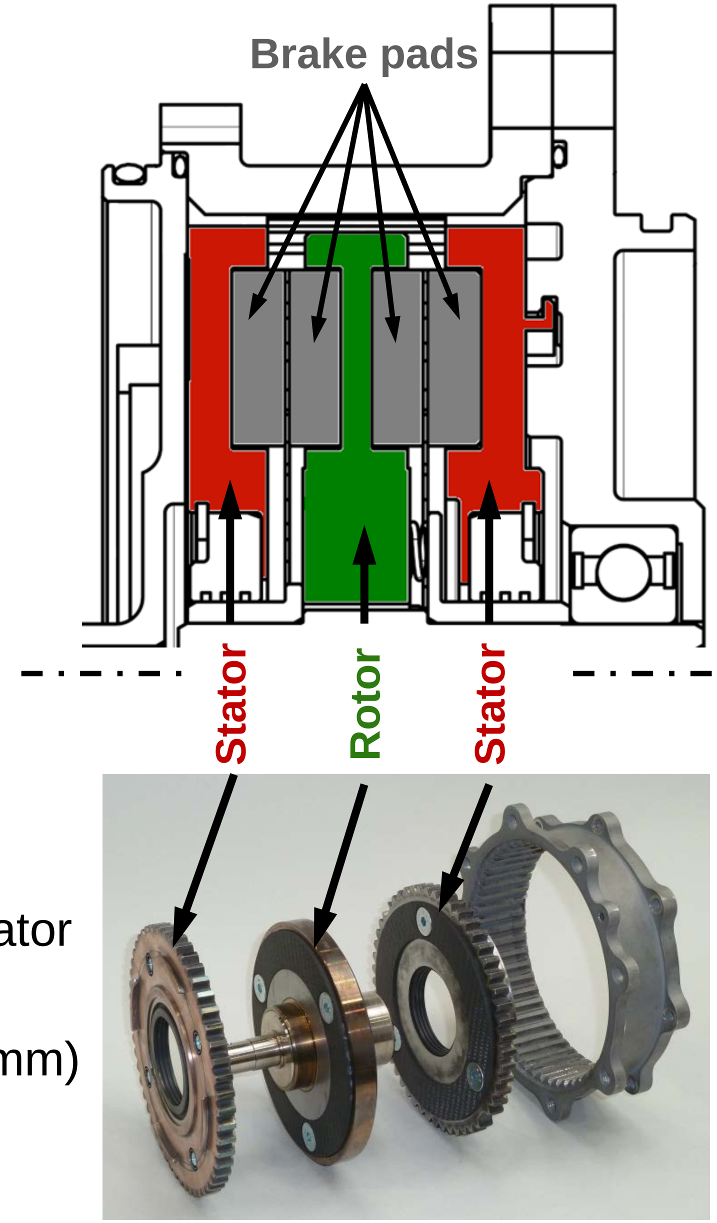
Schindler / FCT

Umbra / SKT

Propeller Brake for A400M



Source:Turboprop_operation.png: Emoscopes



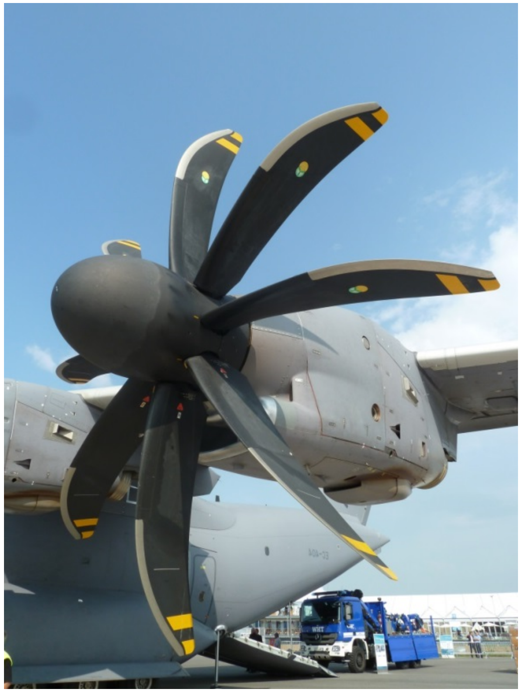
- Compact multidisc brake system (Umbra).
- One rotor disc linked with propeller, two stator discs fixed in brake casing.
- Four C/C-SiC brake pads (Ø 120 mm x 6 mm) rivetted to steel discs.

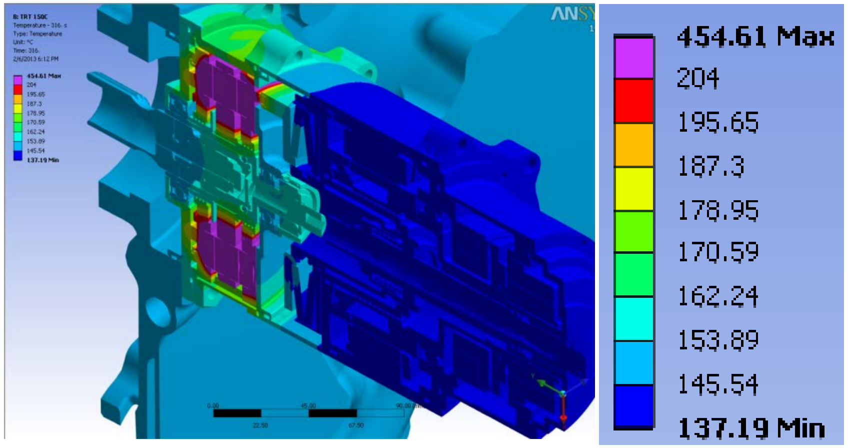
Application

- Propeller stopping after landing / blocking during parking (storm)
- Braking conditions
  - Ø $_{Propeller}$ = 5.3 m
  - $v_{max.} \leq 650$ rpm = 6.3 m/s
  - $p_{max.} \leq 3.2$ MPa
- Requirements
  - $t_{braking} \leq 8$ s → $COF_{dynamic} \geq 0.45$
  - $Wear_{max.} \leq 0.27$ mm³/kJ^{-1}
  - $COF_{static} > 0.25$
  - $E_{max.} > 100$ kJ

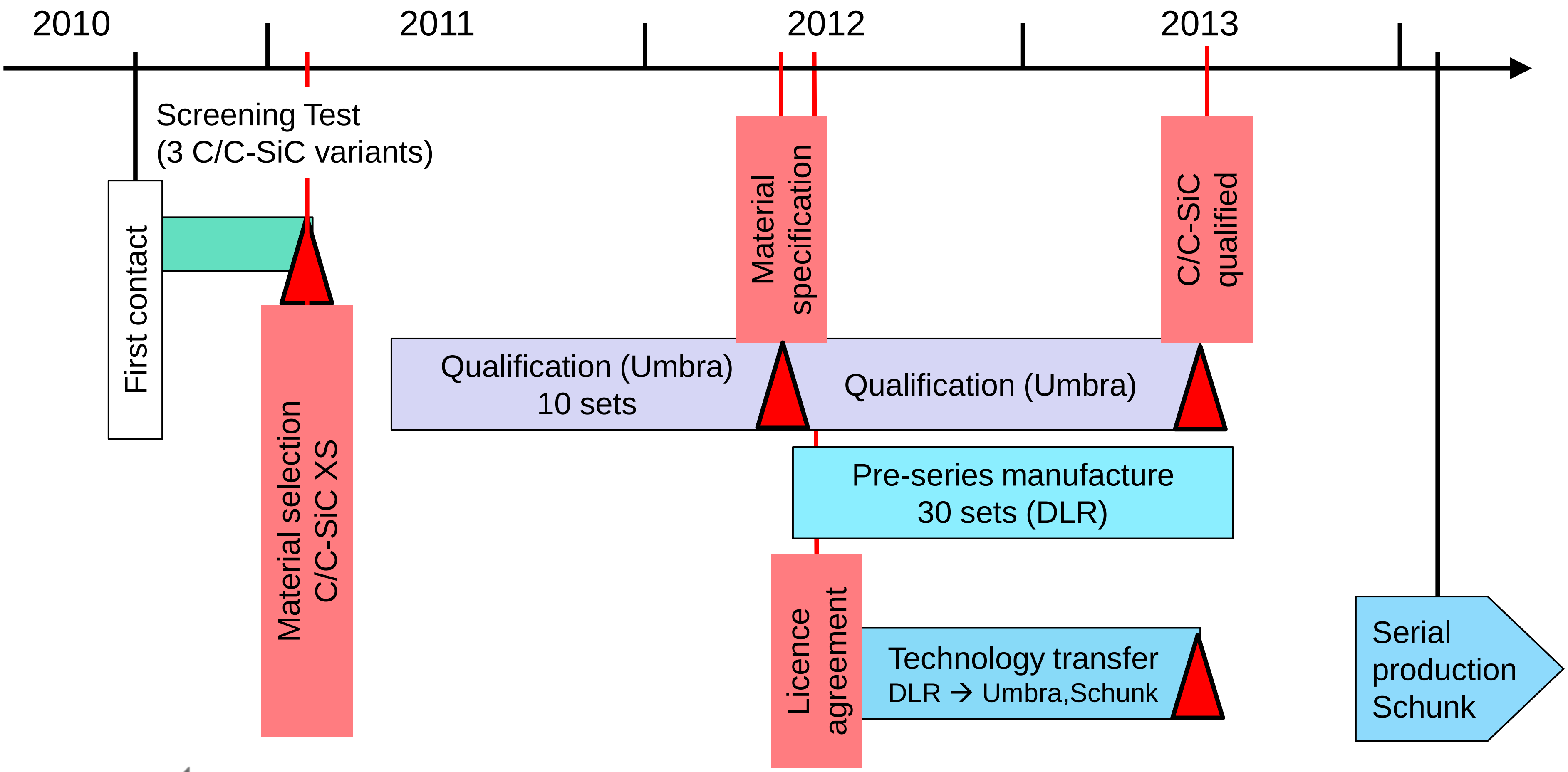
⇨ $T_{max.} > 450$ °C

⇨ CMC brake pads





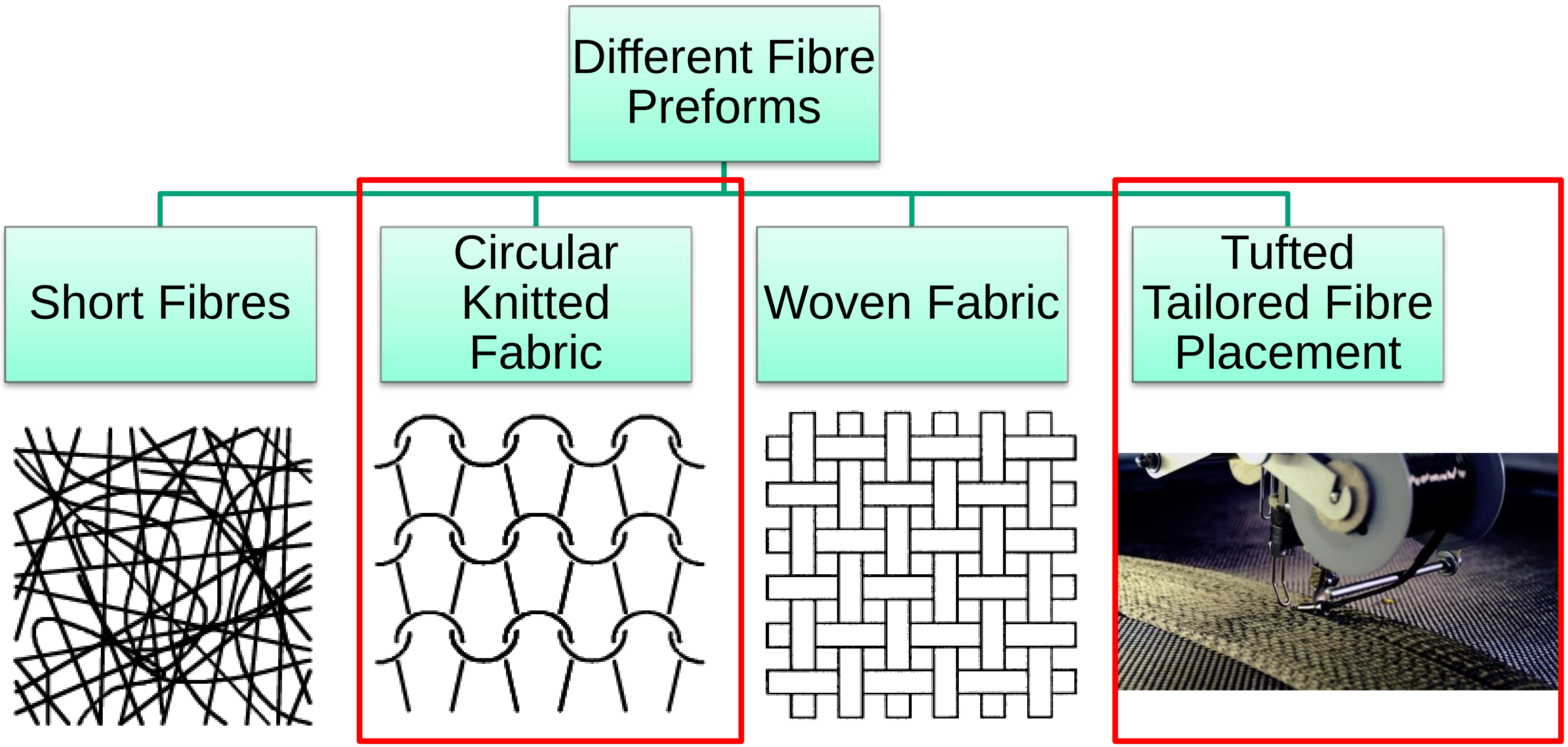
Development of C/C-SiC prake pads



What is next?

- Improved materials based on new fibre preforms
  - Adjustment of temperature distribution (thermal conductivity and thermal capacity)
  - Higher mechanical properties
  - Reprodrucibility
- Sandwich design for lightweight structures and brake discs
- Improvement and prediction of corrosion resistance
- Failure analysis
- Liefetime prediction

Different Fiber Preforms for Ceramic brake disc application



-https://www1.ethz.ch/structures/education/master/intro/compulsory/composites/Skript/151-0307-V4.0-K07_Textile-Halbzeuge.pdf

DLR

Brake Discs Based on Circular Knitted Fabrics

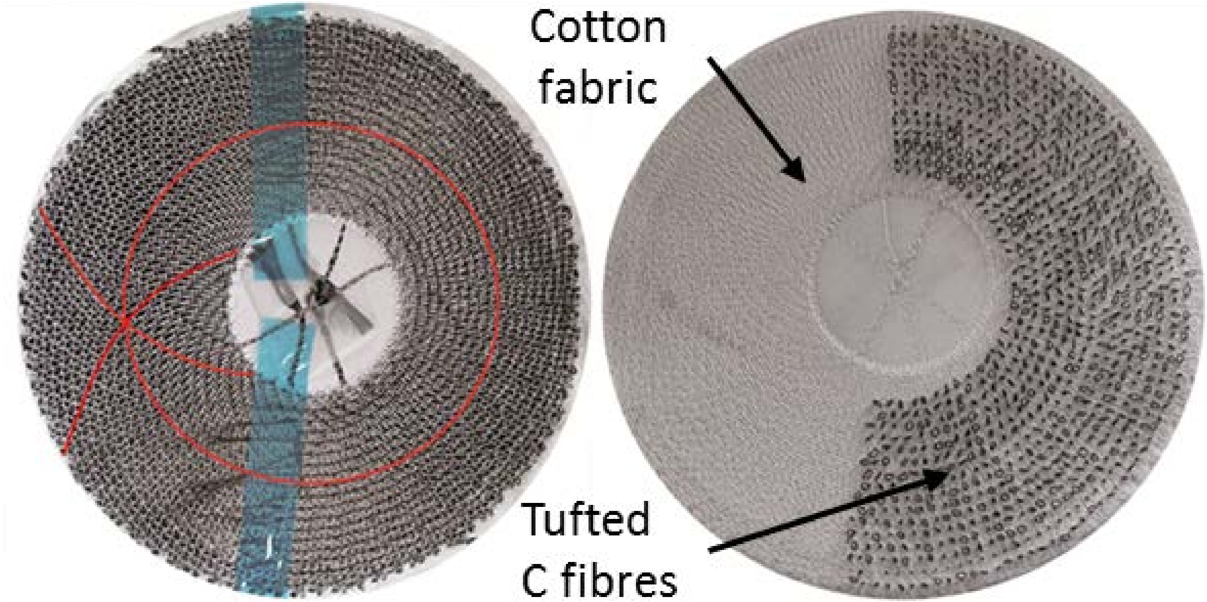
Warm Pressing

Pyrolysis

Siliconization

DLR

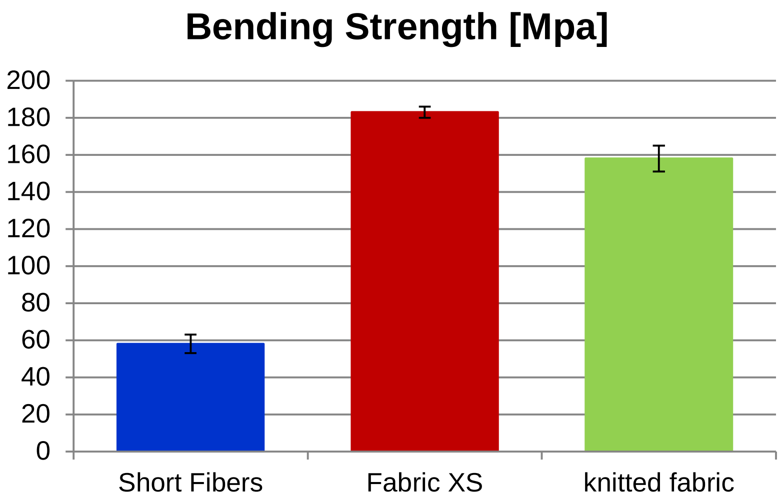
Tufted Fibre Placement (TFP)

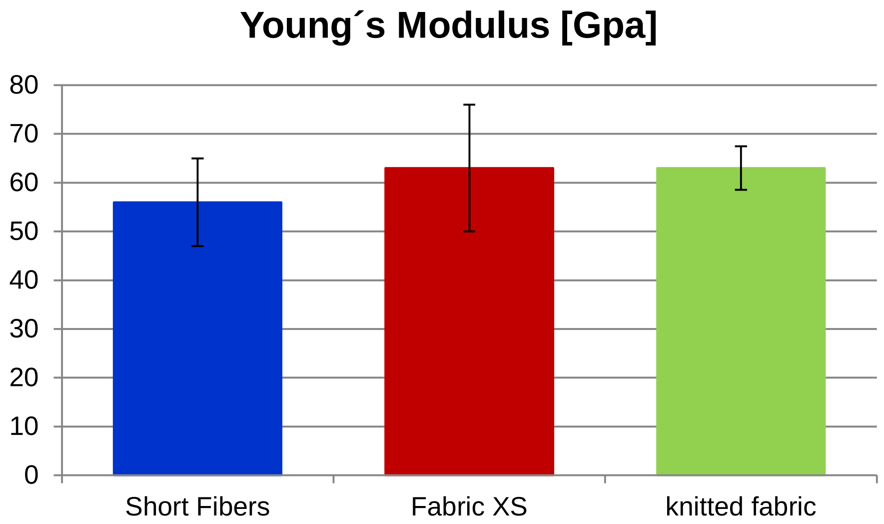


Aims:

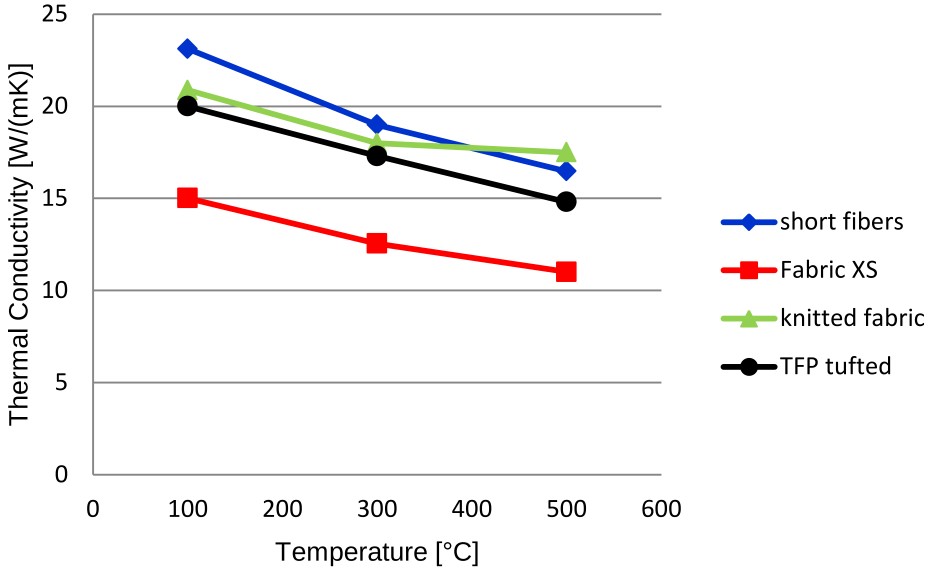
- Higher mechanical properties
- Improved thermal management
- Reproducible Manufacturing

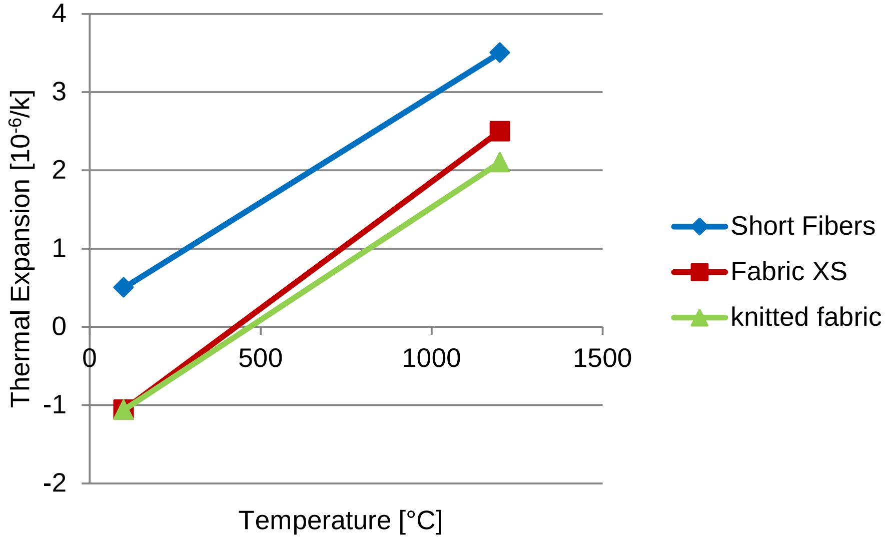
Mechanical Properties



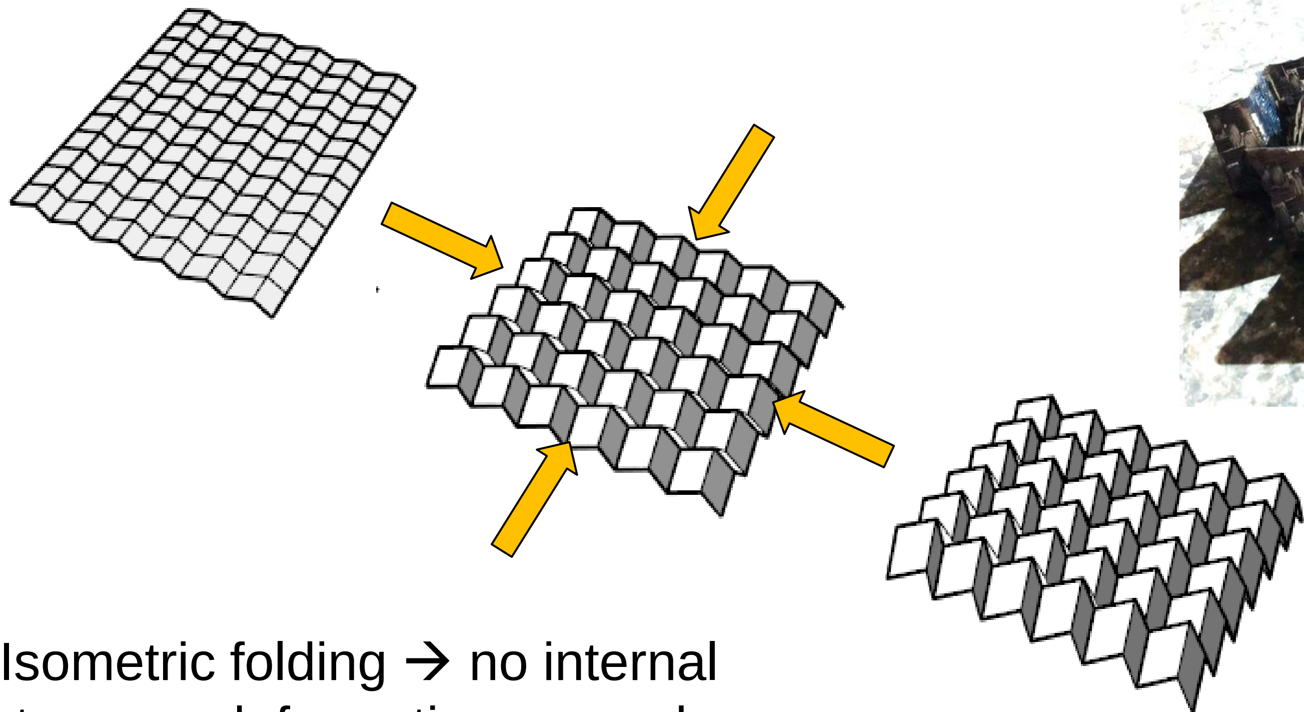


Thermal Properties





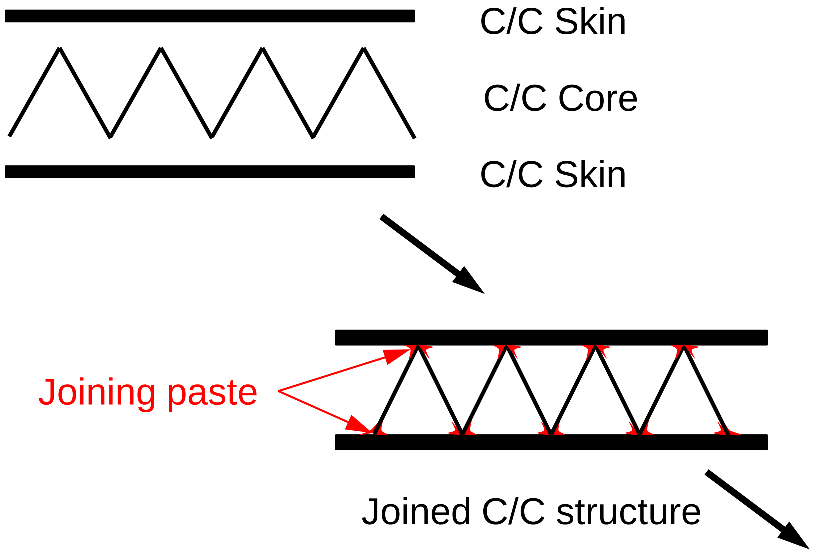
Foldcore Technology



Isometric folding → no internal stresses, deformation or cracks

Y. Klett, University of Stuttgart, Institute of Aircraft Design, 2013

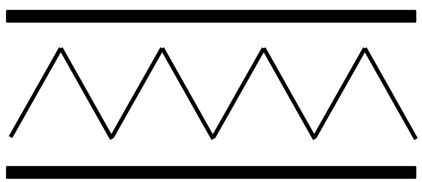
Ventilated Brake Discs Based on Foldcores



C/C-SiC sandwich structure

B. Heidenreich, D. Koch (DLR), N. Gottschalk, Y. Klett (IFB), 2016

Ventilated Brake Discs Based on Foldcores

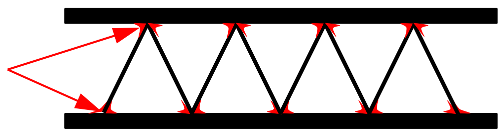


C/C Skin

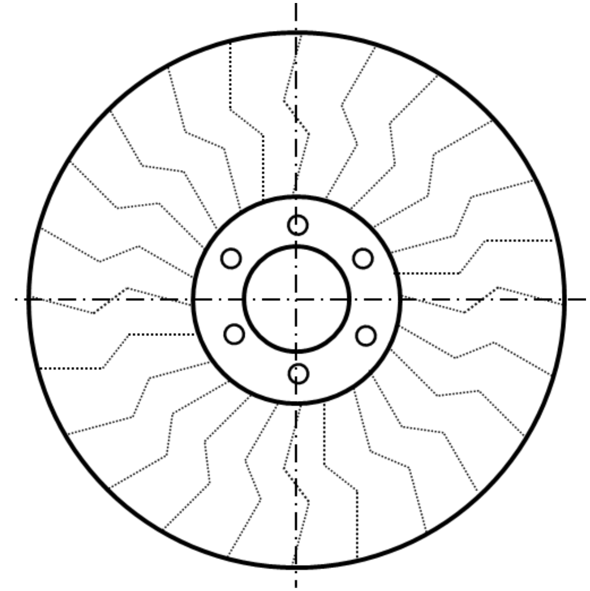
C/C Core

C/C Skin

Joining paste



Joined C/C structure



C/C-SiC sandwich structure

B. Heidenreich, D. Koch (DLR), N. Gottschalk, Y. Klett (IFB), 2016