CMC Materials for Aircraft Brakes

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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

- 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 production
- Advanced braking systems for heavy and fast cars, escalators, trains, planes
Manufacturing Process: Liquid Silicon Infiltration

- **Precursor**: Silicon Granules
- **Additives**: CFRP
- **Fibers**: Pyrolysis
  - $T < 250 \, ^\circ C$
- **Silicon Granules**: Siliconization
  - $T > 900 \, ^\circ C$
  - $T > 1500 \, ^\circ C$

CFRP (Shaping)

Pyrolysis

Siliconization

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

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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

2 layers, 1100 °C
3 layers, 900 °C
3 layers, 750 °C
10 layers, 600 °C
3 layers, 750 °C
3 layers, 900 °C
2 layers, 1100 °C

Friction surface
~ 60%
Increasing SiC content
~ 40%
Plane of symmetry
~ 40%
Increasing SiC content
~ 60%
Relaxation crack

RTM

Autoclave

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

- 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
  - \( \bar{D}_{\text{Propeller}} = 5.3 \text{ m} \)
  - \( v_{\text{max.}} \leq 650 \text{ rpm} = 6.3 \text{ m/s} \)
  - \( p_{\text{max.}} \leq 3.2 \text{ MPa} \)

- Requirements
  - \( t_{\text{braking}} \leq 8 \text{ s} \rightarrow \text{COF}_{\text{dynamic}} \geq 0.45 \)
  - \( \text{Wear}_{\text{max.}} \leq 0.27 \text{ mm}^3/\text{kJ}^{-1} \)
  - \( \text{COF}_{\text{static}} > 0.25 \)
  - \( E_{\text{max.}} > 100 \text{ kJ} \)

- \( T_{\text{max.}} > 450 \degree \text{C} \)
- CMC brake pads
Development of C/C-SiC prake pads

2010
- First contact
- Material selection C/C-SiC XS
- Screening Test (3 C/C-SiC variants)

2011
- Material specification
- Qualification (Umbra) 10 sets

2012
- Pre-series manufacture 30 sets (DLR)
- Licence agreement
- Technology transfer DLR → Umbra, Schunk
- Qualification (Umbra)

2013
- C/C-SiC qualified
- Serial production Schunk

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What is next?

- Improved materials based on new fibre preforms
  - Adjustment of temperature distribution (thermal conductivity and thermal capacity)
  - Higher mechanical properties
  - Reproducibility

- Sandwich design for lightweight structures and brake discs

- Improvement and prediction of corrosion resistance
- Failure analysis
- Lifetime prediction
Different Fiber Preforms for Ceramic brake disc application
Brake Discs Based on Circular Knitted Fabrics

- Warm Pressing
- Pyrolysis
- Siliconization
Tufted Fibre Placement (TFP)

Aims:

- Higher mechanical properties
- Improved thermal management
- Reproducible Manufacturing
Mechanical Properties

Bending Strength [Mpa]

Young's Modulus [Gpa]
Thermal Properties

- Thermal Conductivity [W/(mK)]
  - Short fibers
  - Fabric XS
  - knitted fabric
  - TFP tufted

- Thermal Expansion [10^-6/k]

Temperature [°C]

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Foldcore Technology

Isometric folding $\rightarrow$ no internal stresses, deformation or cracks

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

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