Life Cycle Performance of a Thermal Protection System C/SiC for Reusable Launch Vehicles

Ralf Knoche, Dietmar Koch, Georg Grathwohl, Ulrich Trabandt*

Ceramic Materials and Components

University of Bremen, Germany

*** EADS Space Transportation**

European Congress on Advanced Materials and Processes
EUROMAT 2005
Prague, CZ, September 5-8, 2005

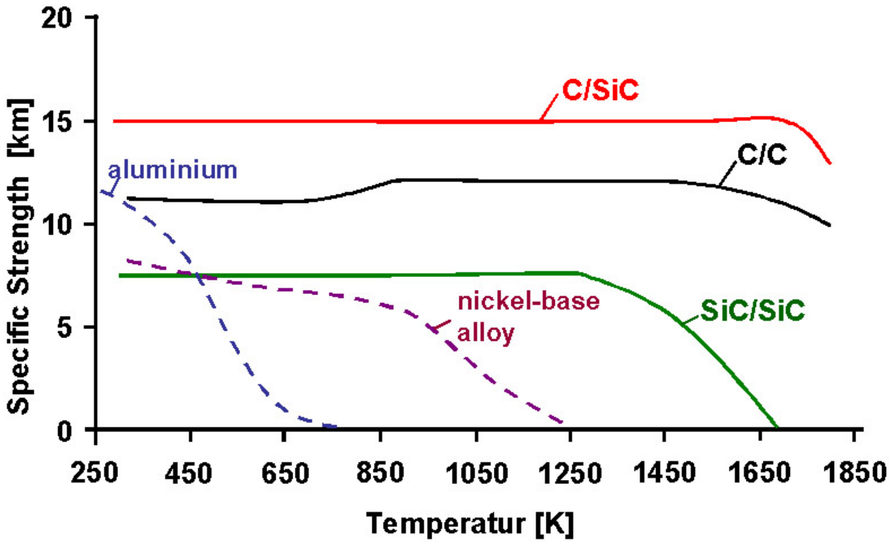
Symposium C34: Materials for Space Applications
Session: Thermal Protection Systems for Reusable Vehicles

Universität Bremen

Keramische Werkstoffe und Bauteile
CERAMICS

Introduction

- Use of C/SiC as Thermal Protection System (TPS) for RLV



W. Schäfer, et al., DGLR Symposium, (1998)

TPS-material	ODS (PM 1000)	γ-TiAl	Oxide based CMC	C/SiC
Max. Reusability Temp. [°C]	1100	850	1200	1600
Density without coating [g/cm^3]	8.2	4.0	2.2	1.8
CTE long. at max. Temp. [K^{-1}]x10^{-6}	17.2	12.7	5.3	2.2

U.Trabandt, et al., Symp. on ARVS, (2005)

Introduction

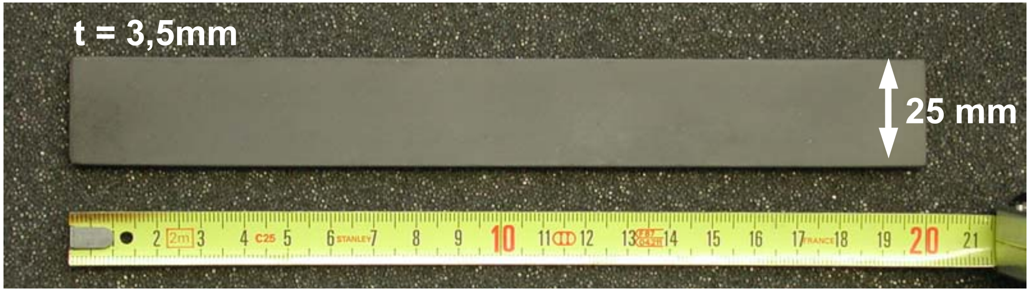
- Use of C/SiC as Thermal Protection System (TPS) for RLV
- Nonoxide CMCs require Oxidation Protection System (OPS)
- Objectives:
  - simulation of thermal and mechanical loads during re-entry
  - thermo-mechanical performance
  - reusability (number of cycles)
  - environmental effects (rain erosion)
  - handling aspects (low speed impact)
  - effectiveness and limitation of TPS

C/SiC as Thermal Protection System (TPS)

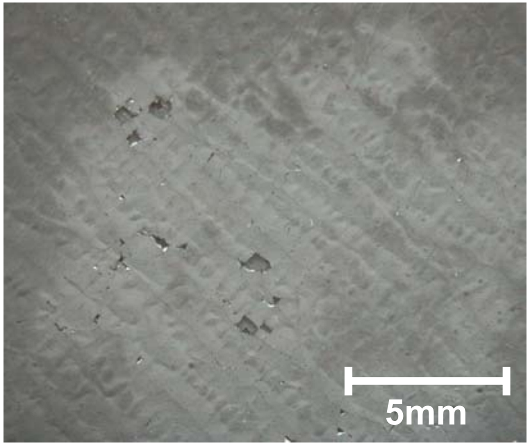
- carbon fibre roving T800 6K (40-45 vol%)
- fibre coating Pyro C
- 16 unidirectional layers in 45° steps (quasi isotropic lay-up)
- SiC (LPI) Matrix
- 10-14% porosity
- multilayer coating as OPS

Test configurations:

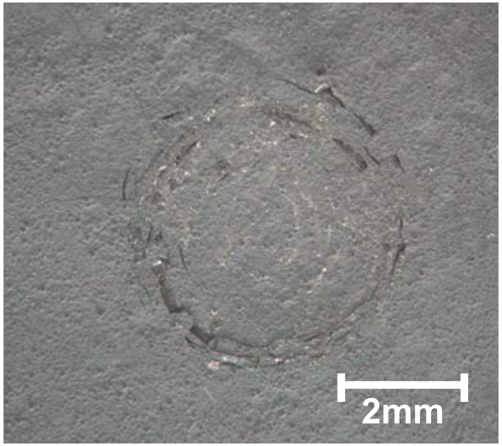
- reference
- rain erosion
- impact
- repaired OPS



Reference specimen



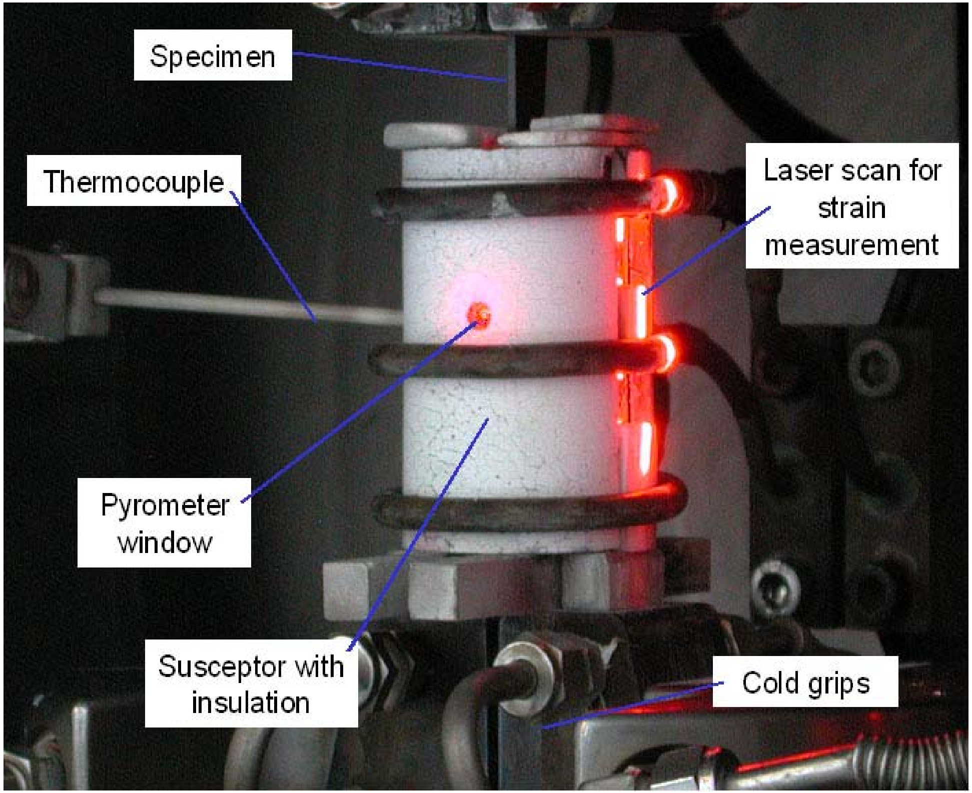
Rain erosion



Impact 0,7J

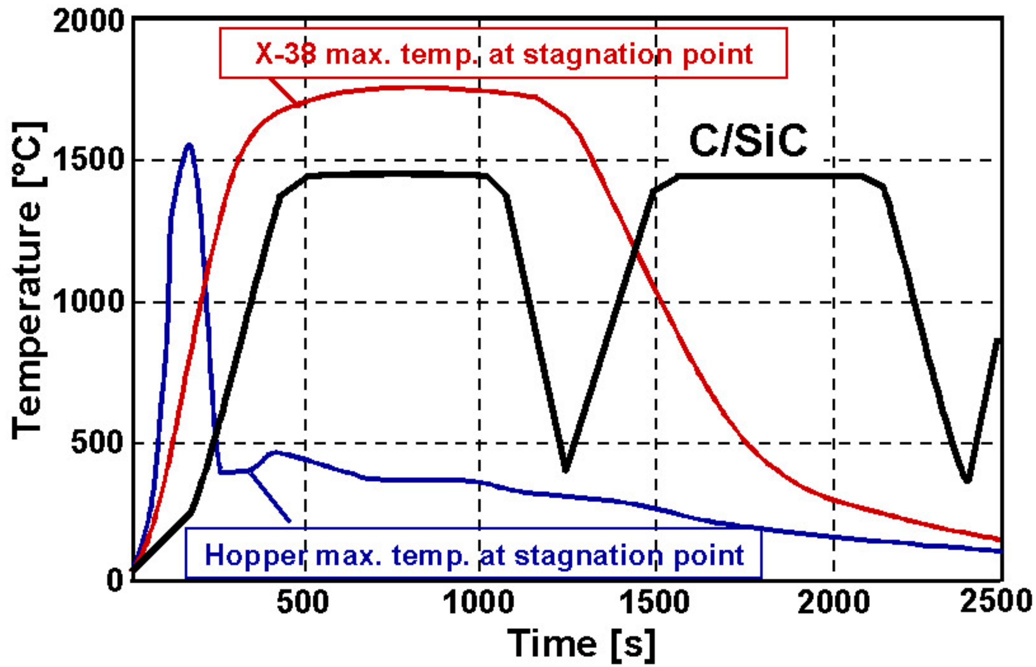
Experimental Setup

- tensile testing machine ZWICK 1465 under displacement control
- inductive heating system (*T*max=1600°C, max. heating rate approx. 100°C/min)
- thermocouples and pyrometer for temperature measurements
- laser extensometer (gauge length 25mm) for contact less strain measurements (up to 1600°C)
- strain gauges for additional strain measurement at room temperature



Test Procedure

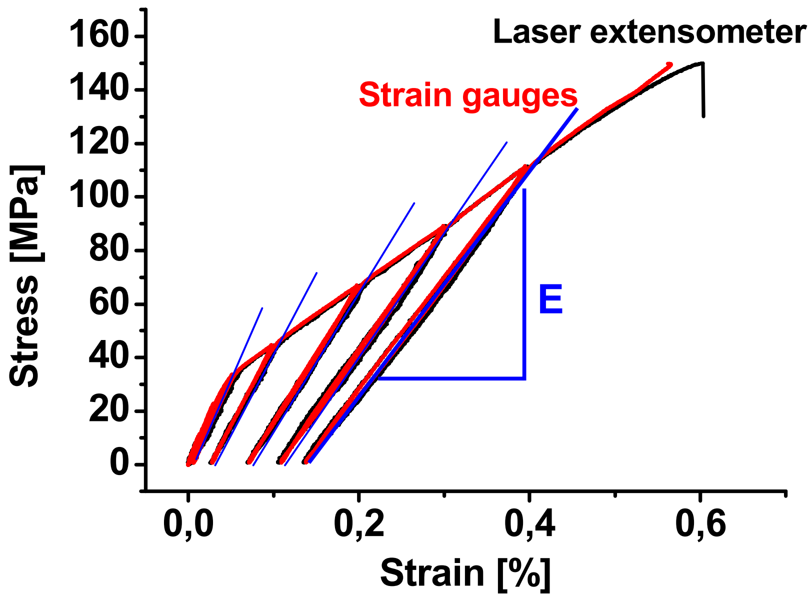
- Initial state tensile tests (Reference Rupture)
- Thermo-mechanical cycling: (1 bar, static tensile load 20% of ultimate rupture load)
  - RT-(400°C-1450°C-400°C)$_x$-RT
  - 1, 5, 10 number of cycles or cycles up to rupture
  - Strain measurements during cycling
  - Mass loss measurements after different numbers of cycles
- Residual strength (RS) measurements

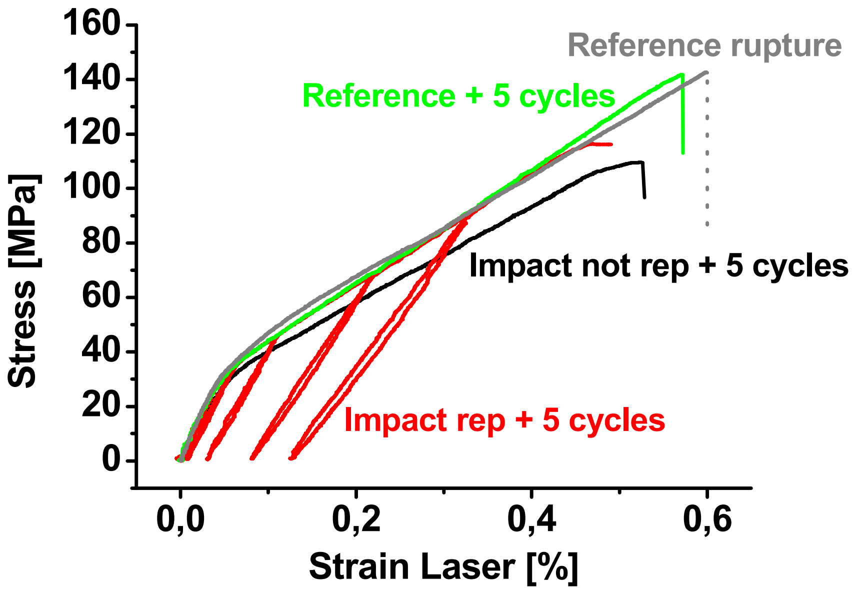


U. Trabandt, et al., HTCMC 5, (2004)

Heating up	**max.1450°C**	**11 min**
Dwell duration	**at 1450°C**	**10 min**
Cooling down	**min 400°C**	**8 min**

Residual Strength Measurement





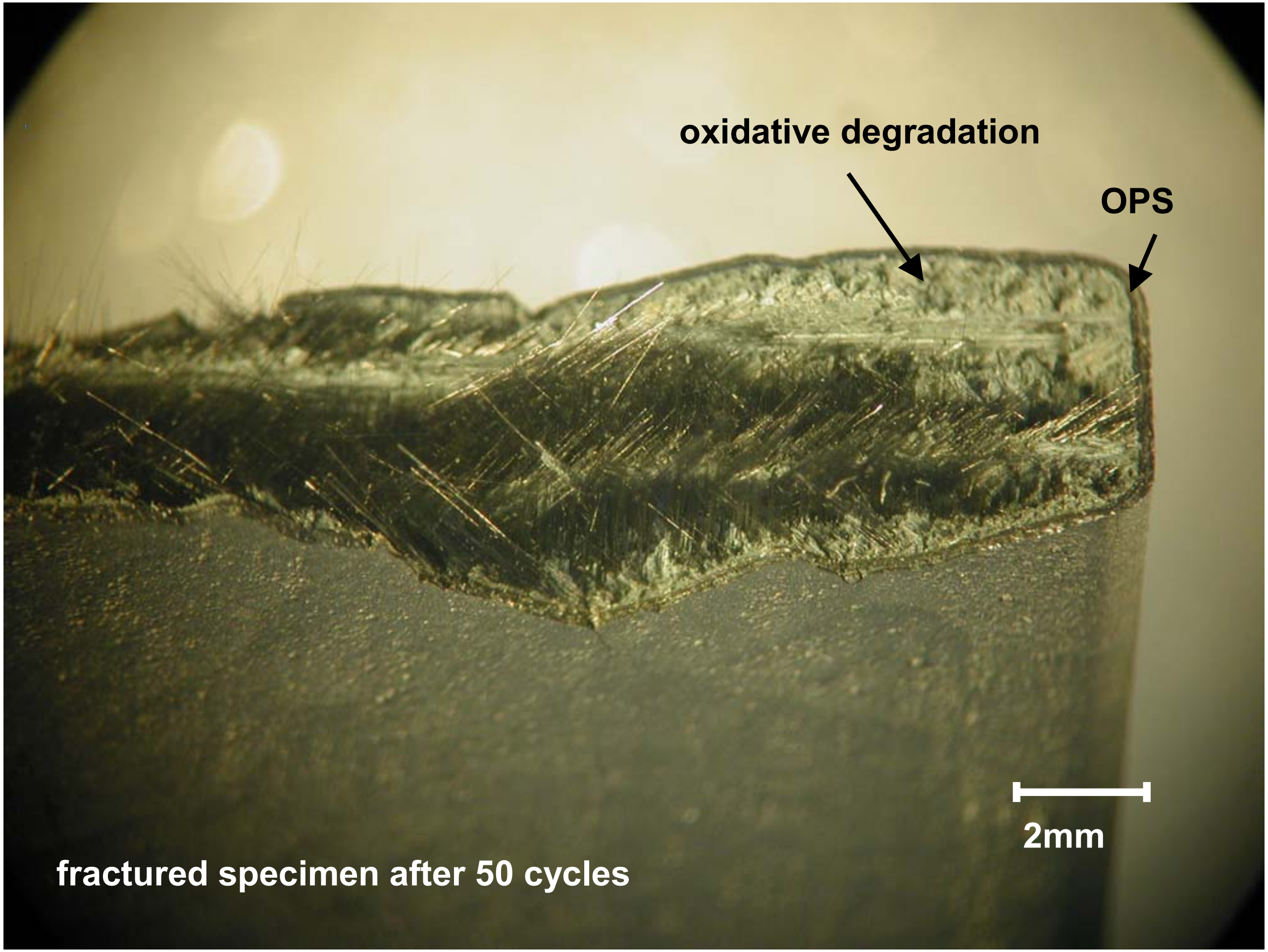
- Young's modulus decrease due to matrix damage during compliance test
- after proportional limit constant slope (tangent modulus) up to failure
- reference and reference + 5 cycles almost identical
- specimens impacted show loss in strength (approx. 20%)
- OPS impact not repaired leads to a decrease in tangent modulus

Thermal Cycling up to Rupture

Test configuration	Number of cycles up to failure	Fracture location
reference (3 samples)	45, 50, 50	bottom edge of inductive heater
impact, not repaired	49	impact area
impact, repaired	55	bottom edge of inductive heater

- no premature failure of configurations impacted → self healing of the OPS works properly at the impact area
- conditions at the edge of the heater are more severe than in the centre of the heater (measuring section) → high thermal gradients combined with a critical temperature pattern induces failure
- number of cycles tolerated can be assumed conservative (except for impact not repaired) → more cycles can be expected with hot grips

Failure Behaviour in long-term Test



Conclusions / Summary

effectiveness of TPS (C/SiC with OPS) under reusable aspects had been investigated

- rain erosion does not have an influence on the TPS performance
- mass loss marks the beginning of oxidative degradation after 25 cycles
- impact leads to an increase in mass loss

  ➡ however, no premature failure during long time cycling
- impact reduces tensile strength
- thermo-mechanical cycling leads to loss in strength and to stiffness reduction
- max numbers of simulated re-entries (over-all) averages 48 !
- OPS shows reduced efficiency below 800°C (alternative TPS-materials available)

OPS (self-healing ability combined with an erosion resistant layer) provide good protection against rain erosion and low speed impact