

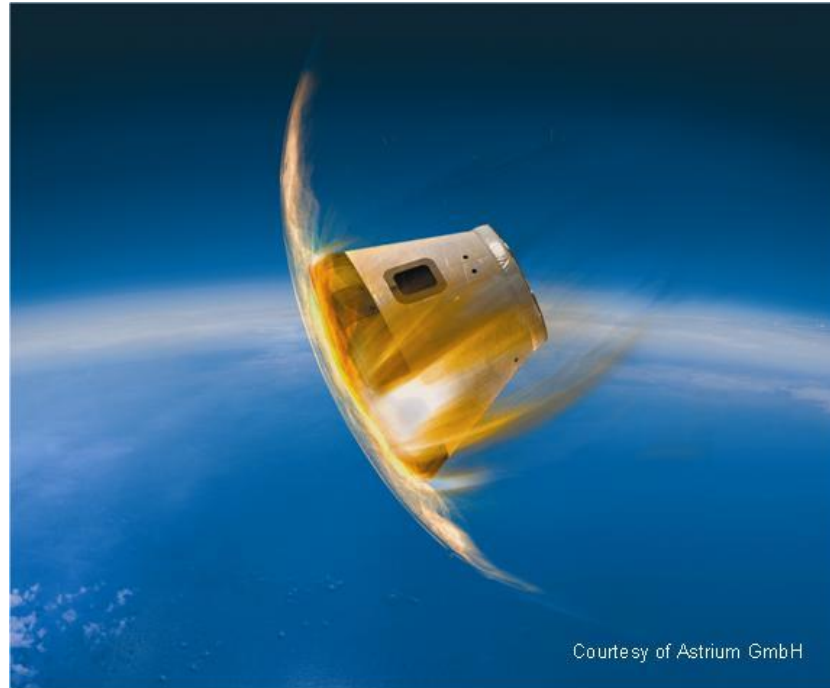


Heterogeneous heteroporous ceramics

A. Ortona, C. D'angelo, **SUPSI**, Switzerland; V. Liedtke, **Aerospace & Advanced Composites**, Austria; C. Wilhelmi, **EADS Innovation Works**, Germany; D. Gaia, **Erbicol**, Switzerland; C. Badini, **Politecnico di Torino**, Italy; W. Fischer, **Astrium**, Germany

- State of the art of TPS
- HHC Concept
- Materials
- Process
- Testing
- Results and discussion

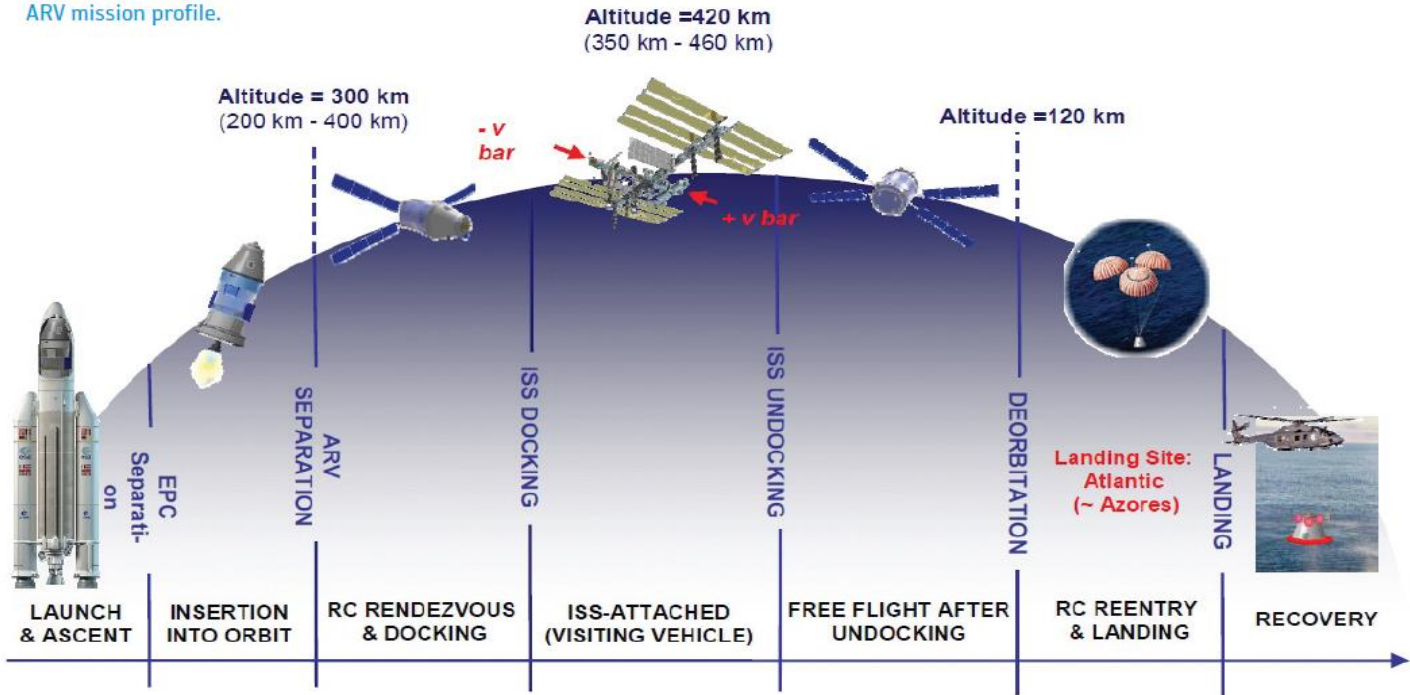
Advanced Re-entry Vehicle



- Re-entry module evolved from ATV. It is a real mission owned by ESA and developed by Astrium GmbH, which consist of a capsule-like concept for a service module to the ISS.
- There are two versions for cargo or crew system. The re-entry will be from LEO (500 km). The first flight will be not reusable and currently there is a trade-off of designs (the currently favoured one is similar to Apollo).

Advanced Re-entry Vehicle

ARV mission profile.



<http://erasmus.spaceflight.esa.int>

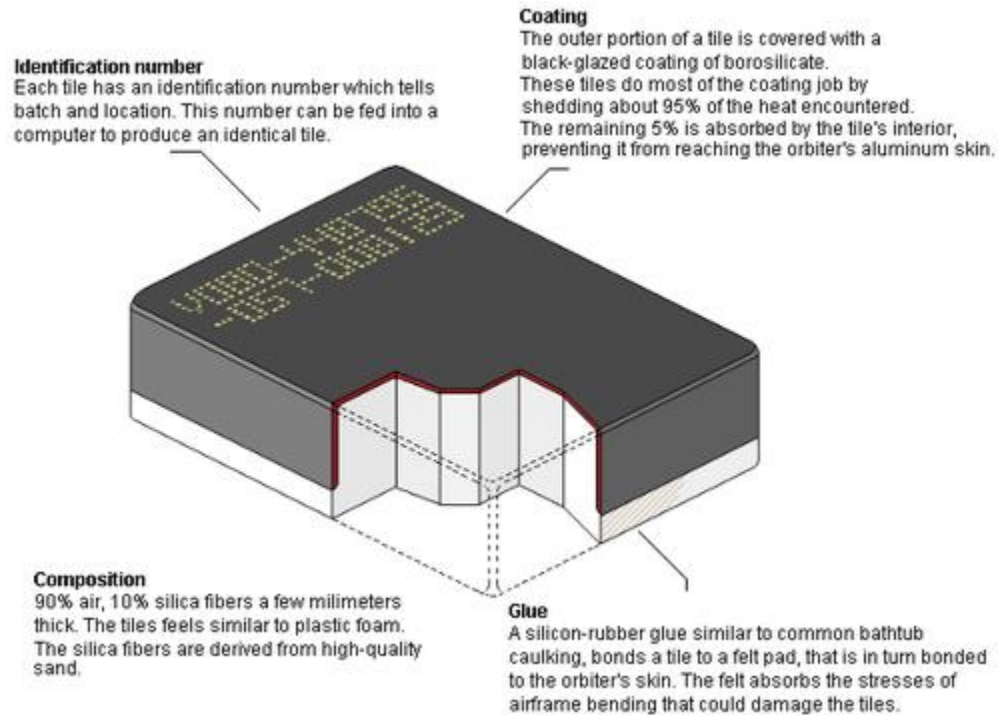
*ARV data have been produced by Astrium GmbH in the frame of a Contract with ESA

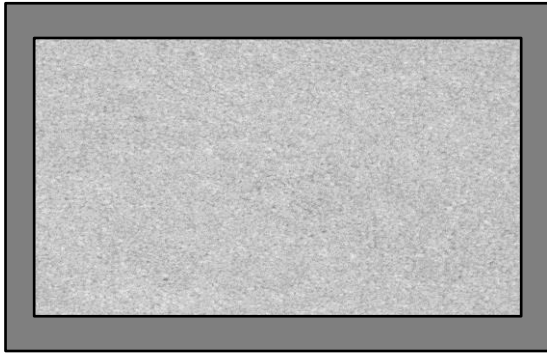
TPS concept can be split in two protection strategies .

1. The **reusable TPS** (RTPS) is adopted for relatively low temperatures when gas velocity and density are relatively low. It needs low thermal conductivity, reflectivity and opacity.
1. The **ablative TPS** (ATPS), dissipates the incoming heat with endothermic chemical reactions of its polymer matrix composite constituent materials. ATPS are adopted when gas velocity, density and thus temperatures are relatively high.

Beside thermal requirements TPS should comply with other design and operational constraints: **structure smoothness** to avoid stress concentrations, **low areal weight**, **low costs** of the component, **low maintenance**, **mechanical and thermal compatibility** with the primary aluminum structure.

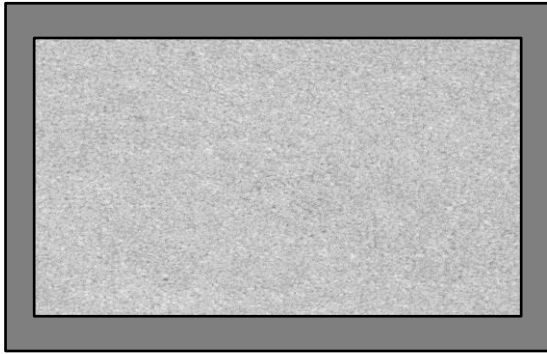
High-temperature reusable surface insulation (HRSI)





Shingle ¹

- 1 Pichon, T., et al., *CMC thermal protection system for future reusable launch vehicles: Generic shingle technological maturation and tests*. *Acta Astronautica*, 2009. **65**(1-2): p. 165-176

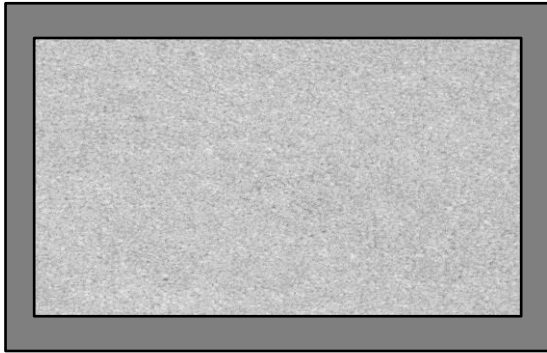


Shingle ¹



Multilayered ²

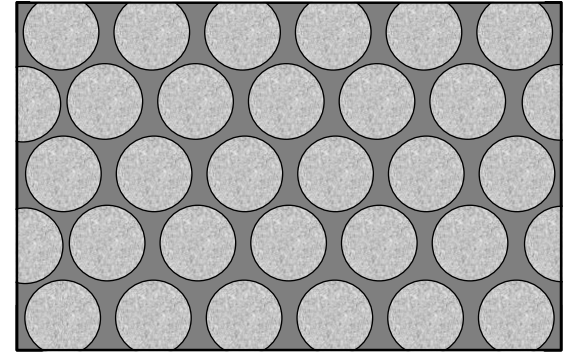
- 1 Pichon, T., et al., *CMC thermal protection system for future reusable launch vehicles: Generic shingle technological maturation and tests*. *Acta Astronautica*, 2009. **65**(1-2): p. 165-176
- 2 Glass, D.E. *Ceramic matrix composite (CMC) thermal protection systems (TPS) and hot structures for hypersonic vehicles*. in *15th AIAA International Space Planes and Hypersonic Systems and Technologies Conference*. 2008. Dayton, OH: AIAA



Shingle ¹

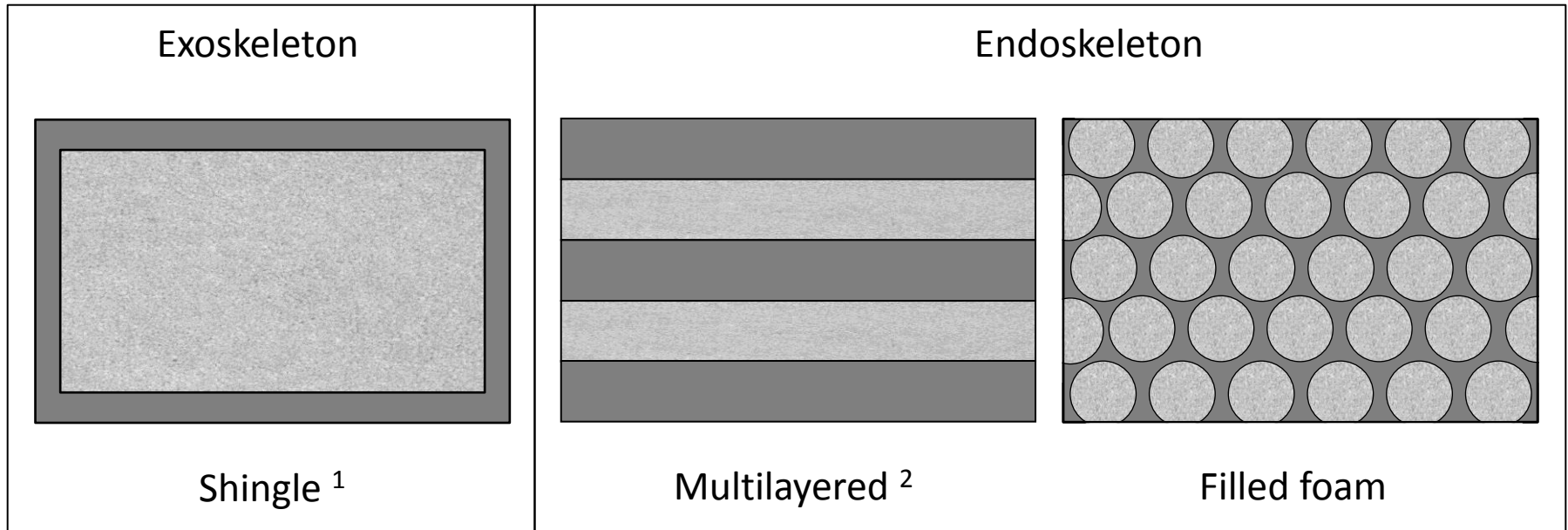


Multilayered ²

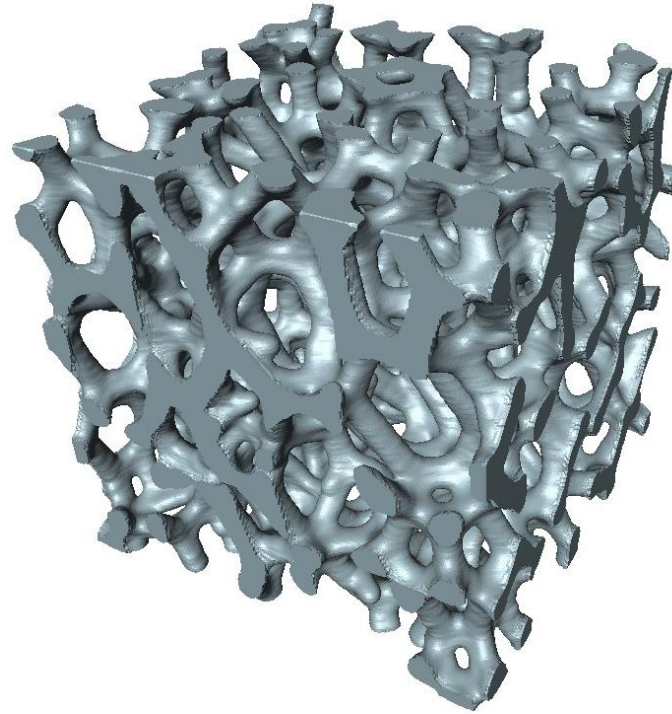


Filled foam

- 1 Pichon, T., et al., *CMC thermal protection system for future reusable launch vehicles: Generic shingle technological maturation and tests*. *Acta Astronautica*, 2009. **65**(1-2): p. 165-176
- 2 Glass, D.E. *Ceramic matrix composite (CMC) thermal protection systems (TPS) and hot structures for hypersonic vehicles*. in *15th AIAA International Space Planes and Hypersonic Systems and Technologies Conference*. 2008. Dayton, OH: AIAA



- 1 Pichon, T., et al., *CMC thermal protection system for future reusable launch vehicles: Generic shingle technological maturation and tests*. *Acta Astronautica*, 2009. **65**(1-2): p. 165-176
- 2 Glass, D.E. *Ceramic matrix composite (CMC) thermal protection systems (TPS) and hot structures for hypersonic vehicles*. in *15th AIAA International Space Planes and Hypersonic Systems and Technologies Conference*. 2008. Dayton, OH: AIAA



Materials: Si-SiC foams

Property		Value
Foam Density	[gcm ⁻³]	0.323
Normalized Density		0.114
Macroporosity	[%]	88.6
Surface Area	[m ² m ⁻³]	~ 500
Av. Strut Thickness	[mm]	0.9
Flexural Strength (3 point)	[MPa]	4
Compression Strength	[MPa]	3
Thermal Conductivity	[Wm ⁻¹ K ⁻¹]	~ 7
Young module (computed)	[GPa]	2-3

10 PPI ErbiSiC foam (Erbicol SA, Balerna, CH)

Fibermax (Unifrax, Rainford, UK)

Typical Chemical Analysis [wt.%]

Al ₂ O ₃	72%
SiO ₂	27%
Fe ₂ O ₃ Trace	0.02%
TiO ₂ Trace	0.001%
MgO	0.05%
CaO	0.05%
Na ₂ O ₃	0.10%

Classification Temperature [°C] * 1600

Fibre Diameter [µm] 4.0 - 6.0

Permanent Linear Shrinkage [%] 24 hour soak

1500 °C 0.7

Density [kg/m³] 100 130

Thermal Conductivity [Wm⁻¹K⁻¹]

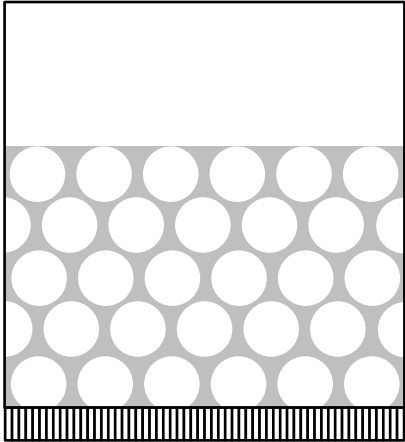
Mean Temp.

800 °C 0.20 0.18

1000 °C 0.29 0.25

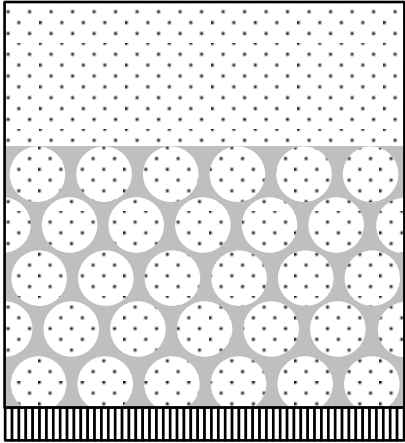
1200 °C 0.42 0.36

Fibers forced sedimentation



Nannetti, C.A., et al., *Manufacturing SiC-Fiber-Reinforced SiC Matrix Composites by Improved CVI/Slurry Infiltration/Polymer Impregnation and Pyrolysis*. Journal of the American Ceramic Society, 2004. **87**(7): p. 1205-1209.

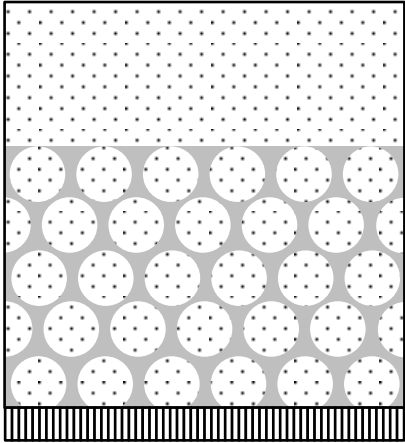
Fibers forced sedimentation



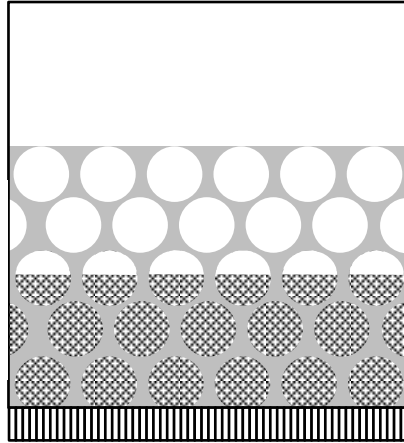
Pouring the suspension

Nannetti, C.A., et al., *Manufacturing SiC-Fiber-Reinforced SiC Matrix Composites by Improved CVI/Slurry Infiltration/Polymer Impregnation and Pyrolysis*. Journal of the American Ceramic Society, 2004. **87**(7): p. 1205-1209.

Fibers forced sedimentation



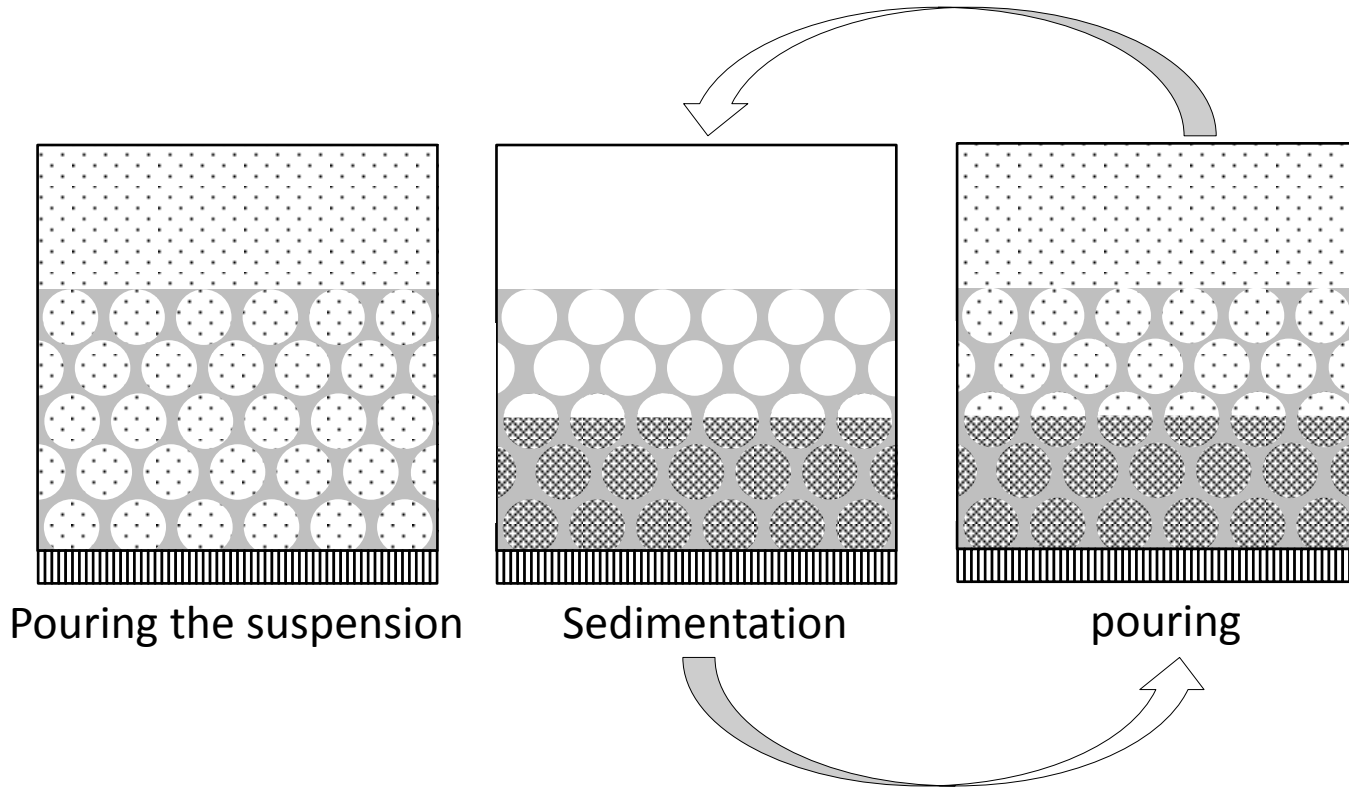
Pouring the suspension



Sedimentation

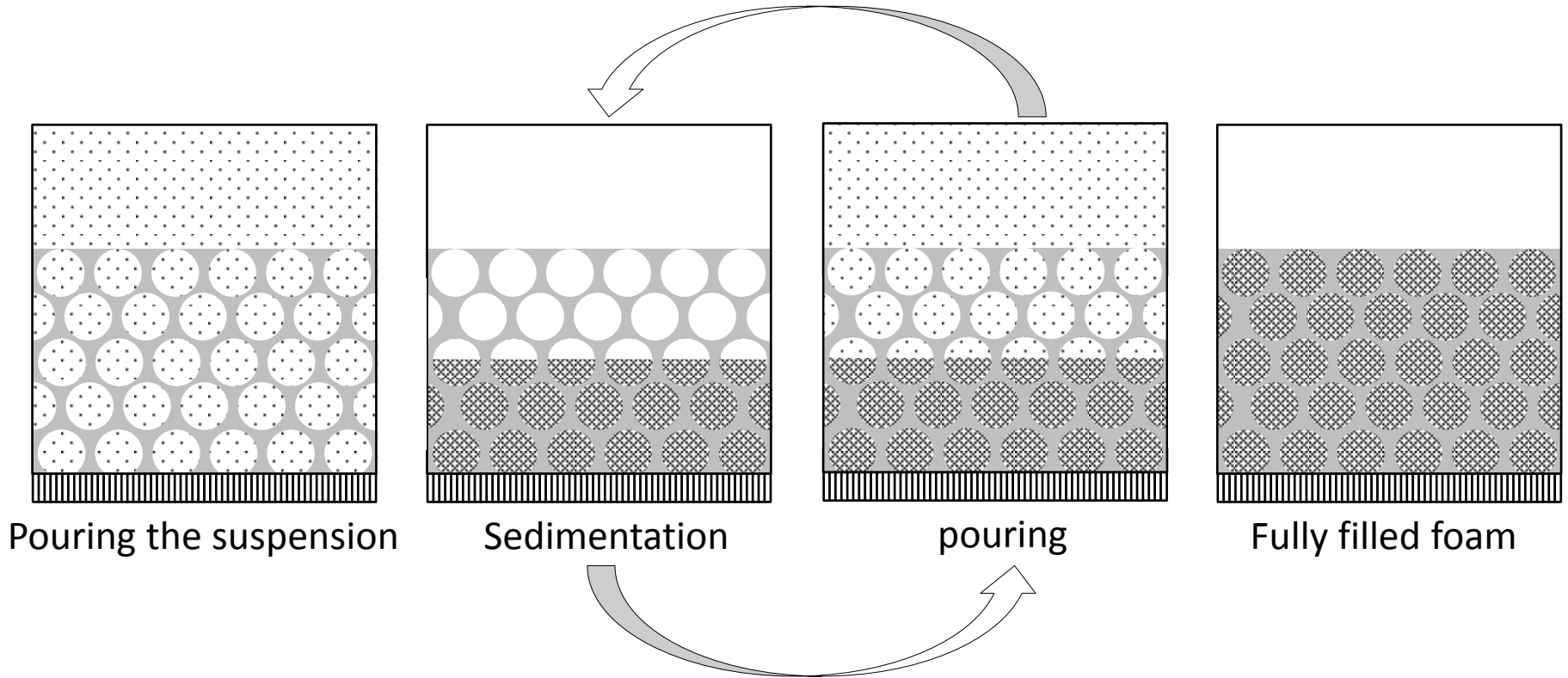
Nannetti, C.A., et al., *Manufacturing SiC-Fiber-Reinforced SiC Matrix Composites by Improved CVI/Slurry Infiltration/Polymer Impregnation and Pyrolysis*. Journal of the American Ceramic Society, 2004. **87**(7): p. 1205-1209.

Fibers forced sedimentation

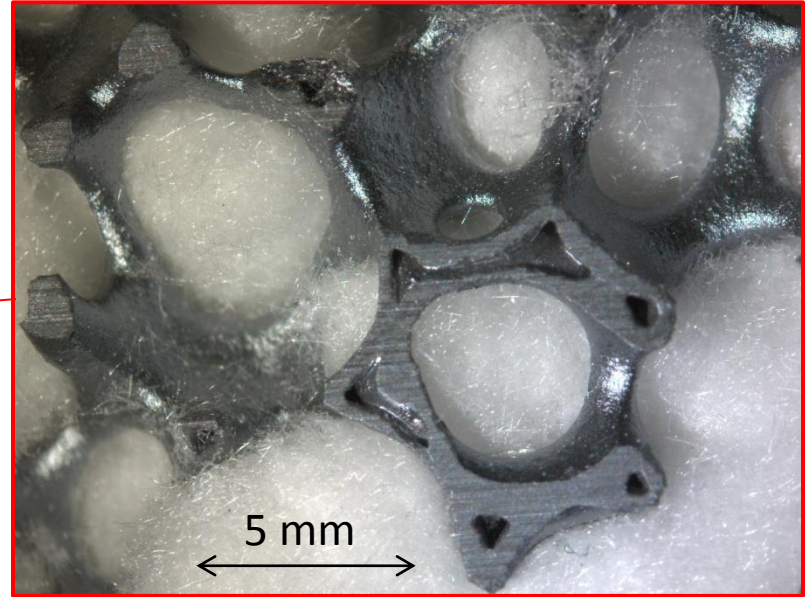
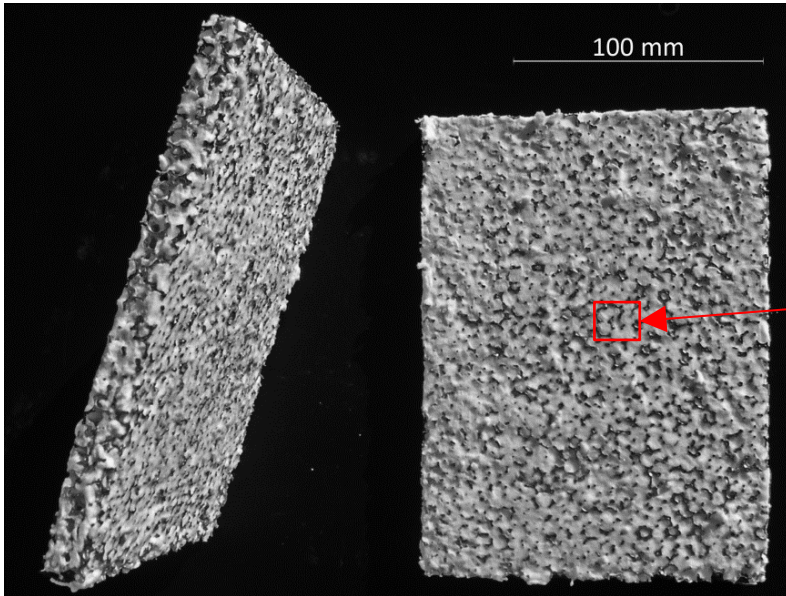


Nannetti, C.A., et al., *Manufacturing SiC-Fiber-Reinforced SiC Matrix Composites by Improved CVI/Slurry Infiltration/Polymer Impregnation and Pyrolysis*. Journal of the American Ceramic Society, 2004. **87**(7): p. 1205-1209.

Fibers forced sedimentation



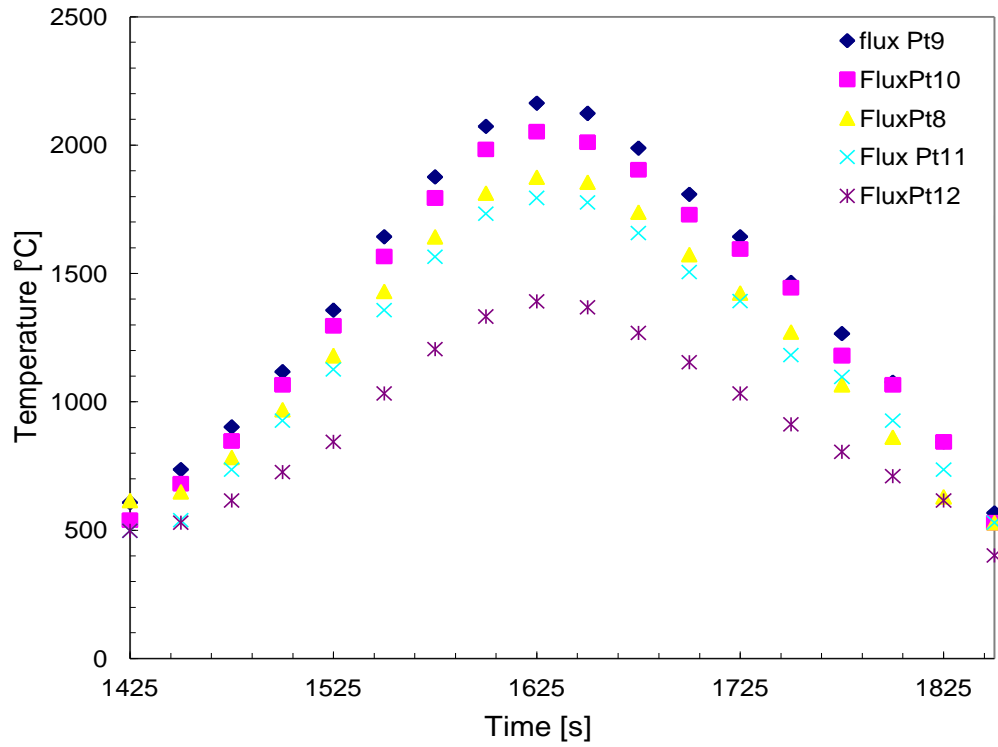
Nannetti, C.A., et al., *Manufacturing SiC-Fiber-Reinforced SiC Matrix Composites by Improved CVI/Slurry Infiltration/Polymer Impregnation and Pyrolysis*. Journal of the American Ceramic Society, 2004. **87**(7): p. 1205-1209.



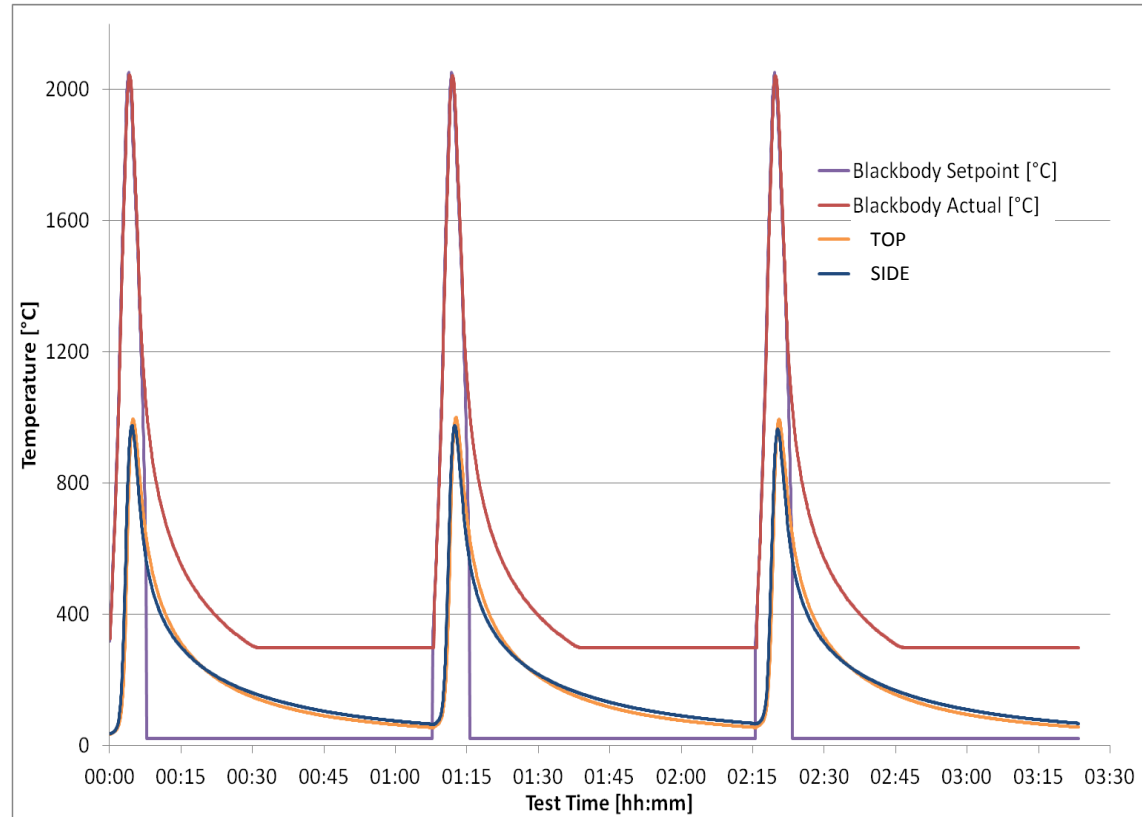
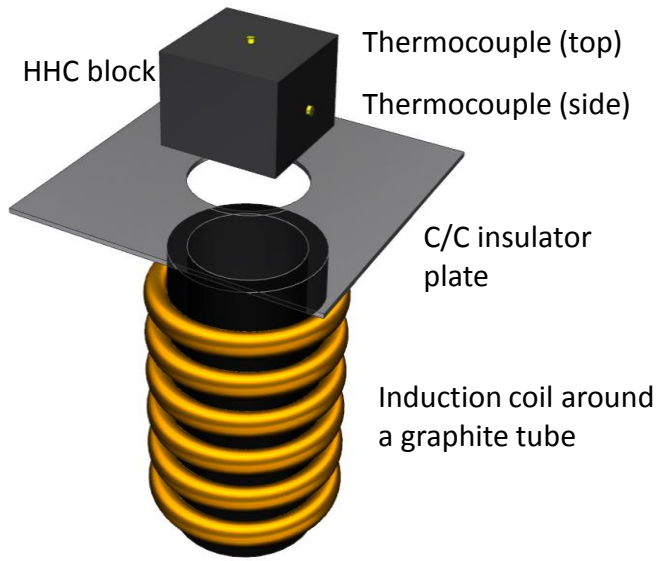
HHC close up

sample #	Foam					filler		HHC
	Mass [g]	L [mm]	w [mm]	t [mm]	ρ [g cm ⁻³]	ρ [g cm ⁻³] · 10 ⁻⁴	w%	ρ [g cm ⁻³]
1	5.18	30.02	29.94	15.20	0.38	3.27	0.43	0.66
2	5.28	30.00	30.20	14.75	0.40	2.69	0.37	0.63
3	5.59	30.04	30.10	15.04	0.41	1.96	0.29	0.58
4	4.92	30.00	30.00	15.25	0.36	2.84	0.41	0.61
5	5.91	30.06	29.86	14.93	0.44	1.96	0.27	0.61
6	5.69	30.20	30.18	15.12	0.41	2.12	0.31	0.59
<i>Average</i>	<i>5.43</i>	<i>30.05</i>	<i>30.05</i>	<i>15.05</i>	<i>0.40</i>	<i>2.47</i>	<i>0.35</i>	<i>0.61</i>

Thermal cycling



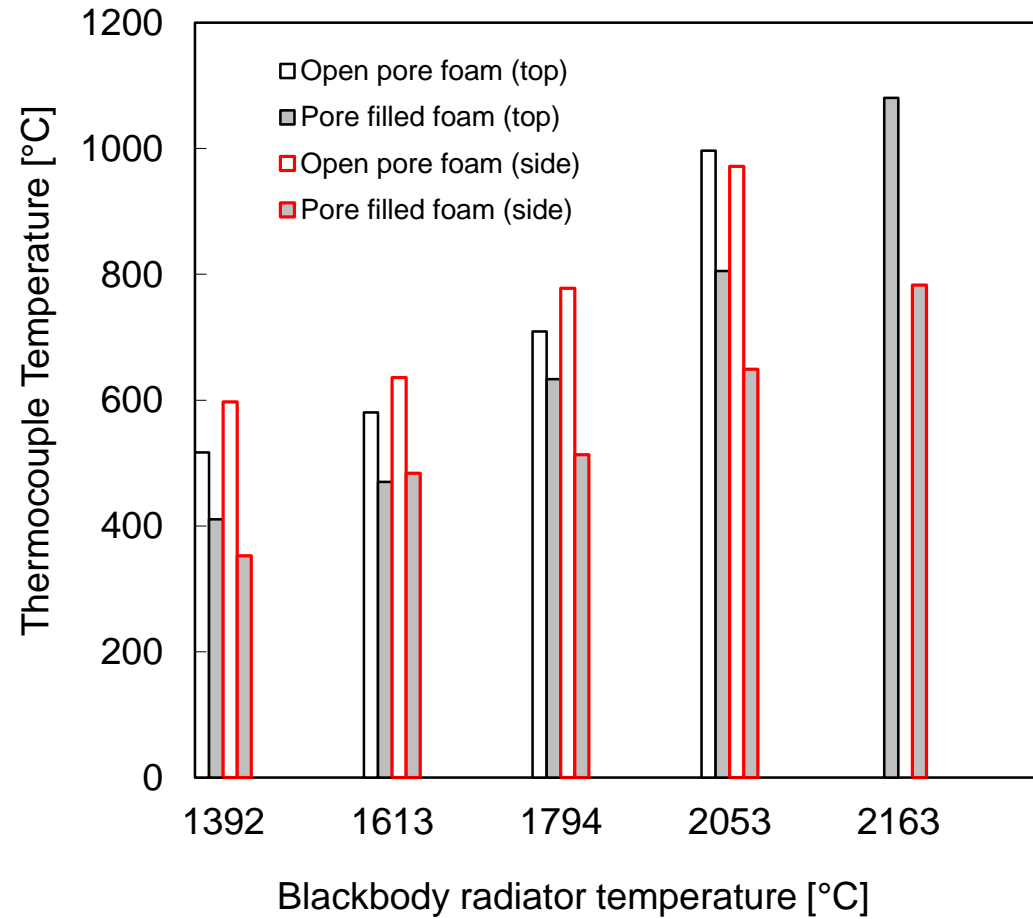
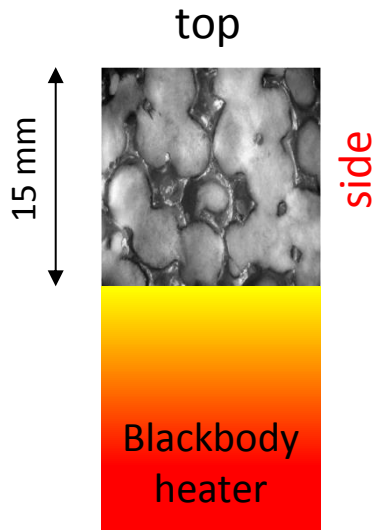
Thermal cycling



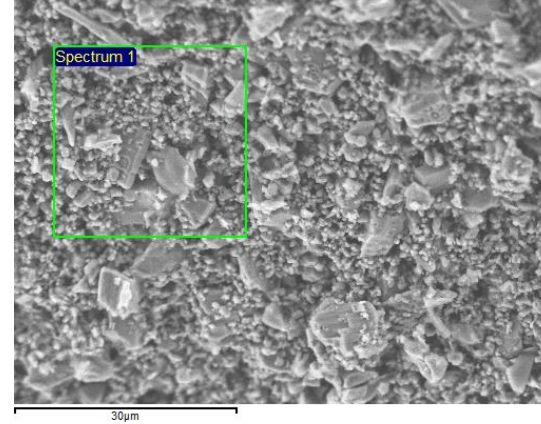
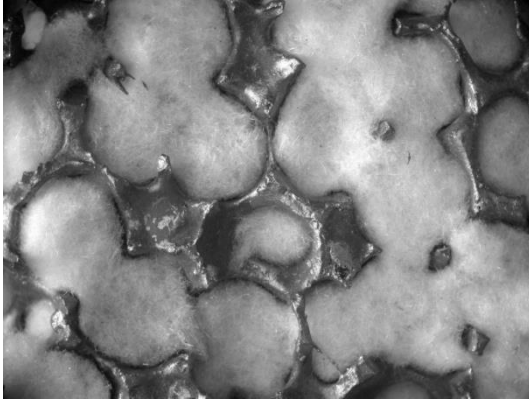
Thermal loading was performed in a vacuum chamber (10^{-4} mbar) equipped with an inductively heated blackbody radiator. Blackbody radiator temperature was monitored with a pyrometer

Thermal Profile		Cycle No.	Si-SiC foam		HHC	
Designation	Peak Temp.		Top[°C]	Side [°C]	Top [°C]	Side [°C]
T12	1392	1	507	589	405	340
		2	521	601	413	357
		3	523	601	414	360
T06	1613	1	576	628	459	475
		2	585	639	475	487
		3	581	641	476	489
T11	1794	1	697	773	619	506
		2	713	779	639	518
		3	718	781	642	516
T10	2053	1	994	975	806	656
		2	1001	975	805	637
		3	994	964	805	654
T09	2163	1			1082	763
		2	Not feasible		1078	779
		3			1081	807

Thermal cycling



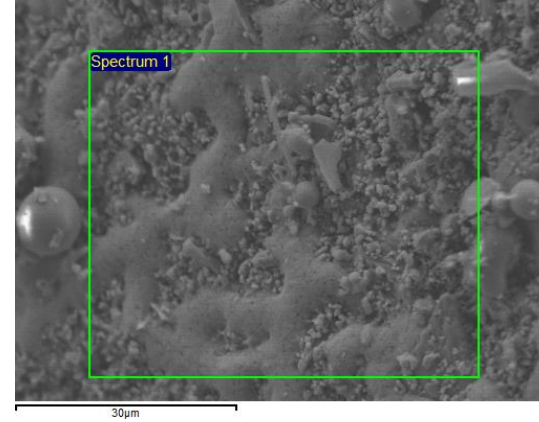
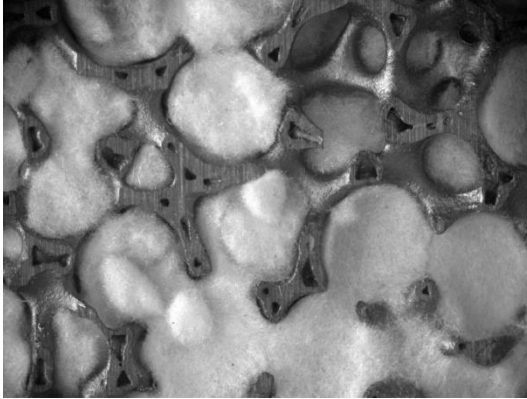
HHC degradation



Element	Atomic %
Na	0,64
Al	2,94
Ca	2,42
O	22,88
C	41,37
Si	29,75

Sample #01 after 3 cycles with profile #06, $T_{\max}=1,613$ °C. No changes to as received state.

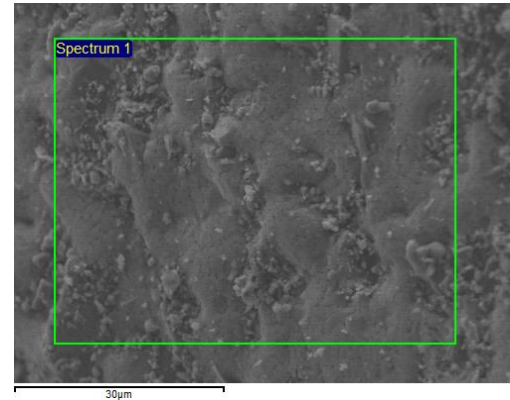
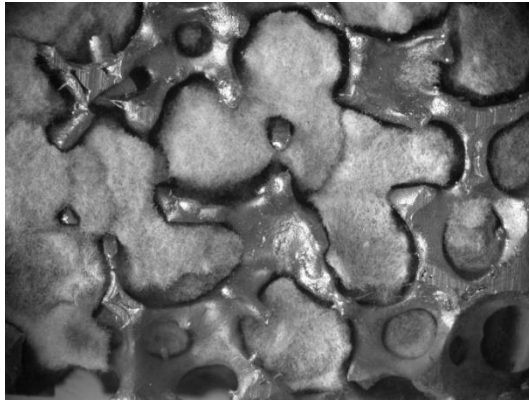
HHC degradation



Element	Atomic %
Al	1,42
O	10,51
C	31,80
Si	56,28

Sample #02 after 3 cycles with profile #11, $T_{\max}=1,794$ °C. No changes to as received state.

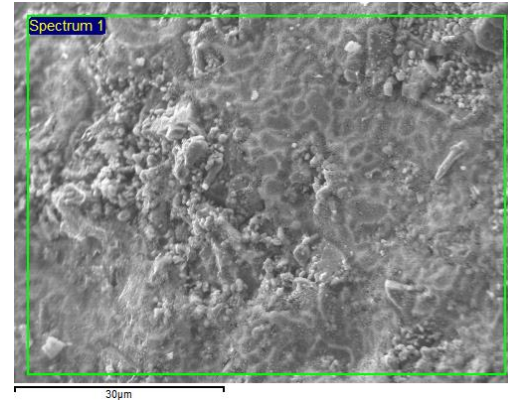
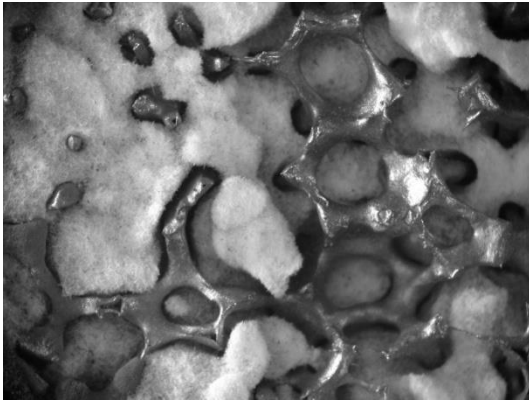
HHC degradation



Element	Atomic %
Al	0,55
O	4,14
C	27,75
Si	67,57

Sample #03 after 3 cycles with profile #10, $T_{\max} = 2,053$ °C. Minor degradation of filler.

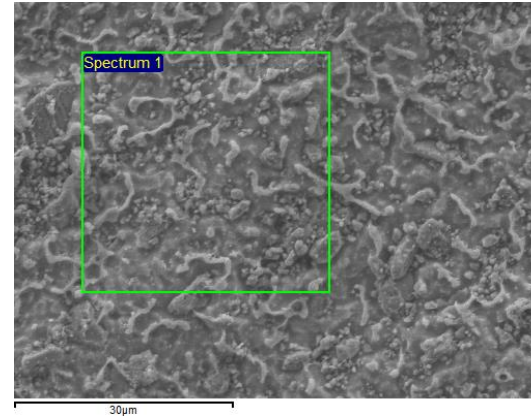
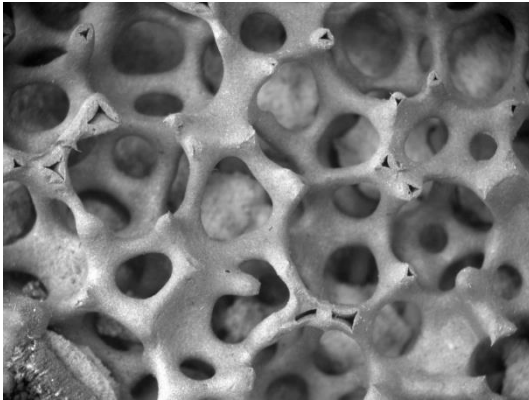
HHC degradation



Element	Atomic %
Al	0,36
O	1,20
C	42,13
Si	56,32

Sample #04 after 10 cycles with profile #10, $T_{\max} = 2,053$ °C. Moderate loss of filler.

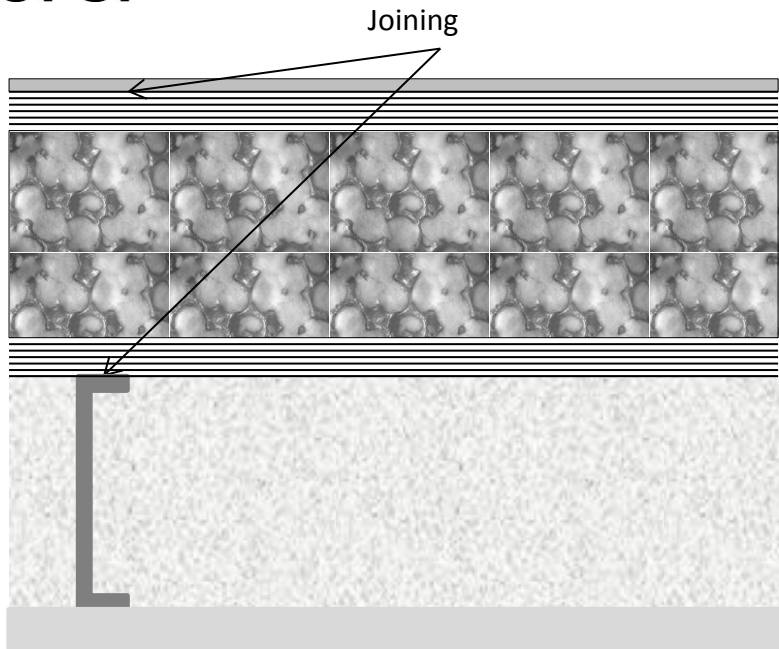
HHC degradation



Element	Atomic %
Al	0,39
O	2,07
C	33,26
Si	64,28

Sample #05 after 10 cycles with profile #09, T_{max}=2,163 °C. Substantial loss of filler, change in SiC

System development



UHTC
CMC

HHC

CMC

Filler + stand off

Frame



Acknowledgements



The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 262749 (Project SMARTTEES).



Hybrid Materials Group at ICIMSI

Dr. ing. Giulio Scocchi

Dr. Danilo Sergi

Ing. Claudio D'Angelo

Ing. Giovanni Bianchi

Ing. Luca Ferrari

Ing. Ehsan Rezaei

materials properties

process simulation

materials properties

experiments set up

thermo fluid dynamics

characterization

*Prof. ing. Alberto Ortona**

University of Applied Sciences (SUPSI)

The iCIMSI Research Institute,

Address:

Telephone:

alberto.ortona@supsi.ch

www.supsi.ch

www.icimsi.ch

Galleria 2, CH 6928, Manno, Switzerland

+41 58 6666611

**Contact*