

HTCMC7

C_f/SiC_m CMC - SiC foam sandwich preparation and characterization

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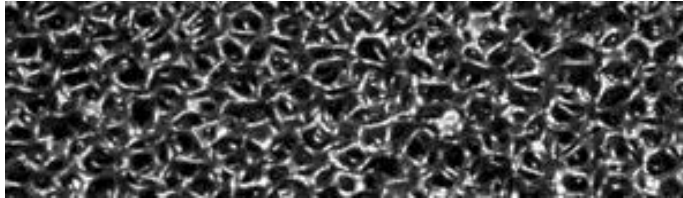
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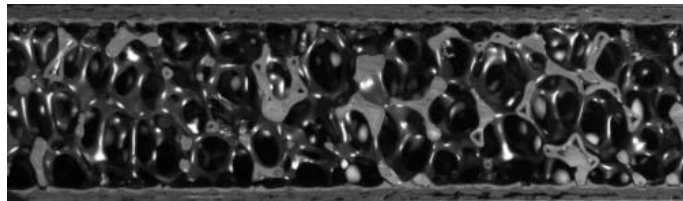
Erbicol SA Viale Pereda 22, 6828, Balerna, Switzerland

Outline

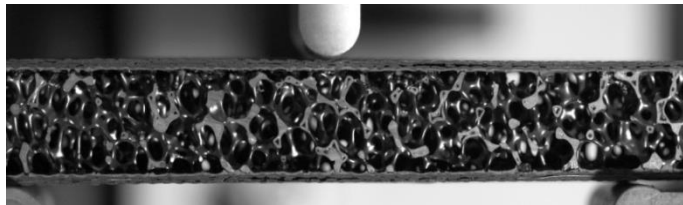
Sandwich structures



Silicon carbide foams



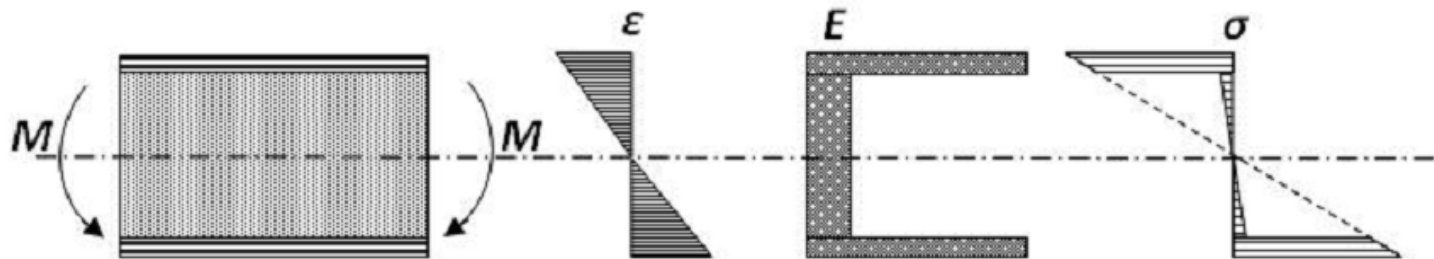
SiC Sandwich assembly



Sandwich characterization

Sandwich structures

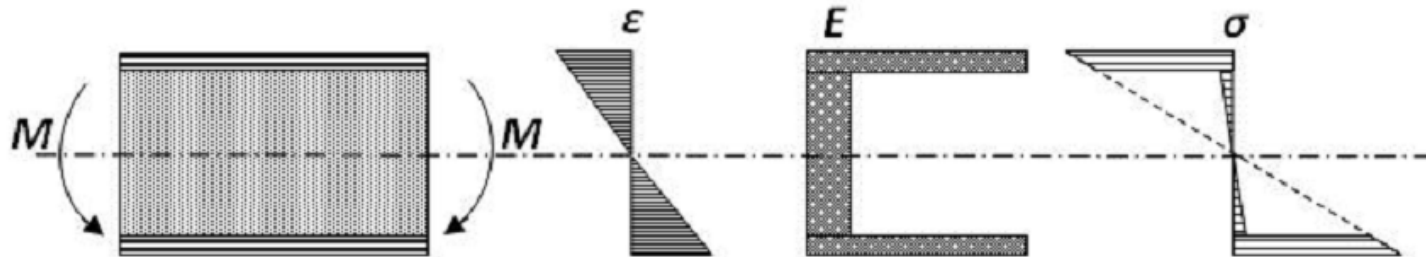
Sandwich structures are very effective because of their high specific stiffness and strength. Polymer based sandwiches are widely used in aeronautics and naval applications



Ceramic (SiC) Sandwich structures

Joining CMC faces to a ceramic core can be achieved by:

- mechanical fasteners
- glasses
- brazing alloys
- pre-ceramic polymers

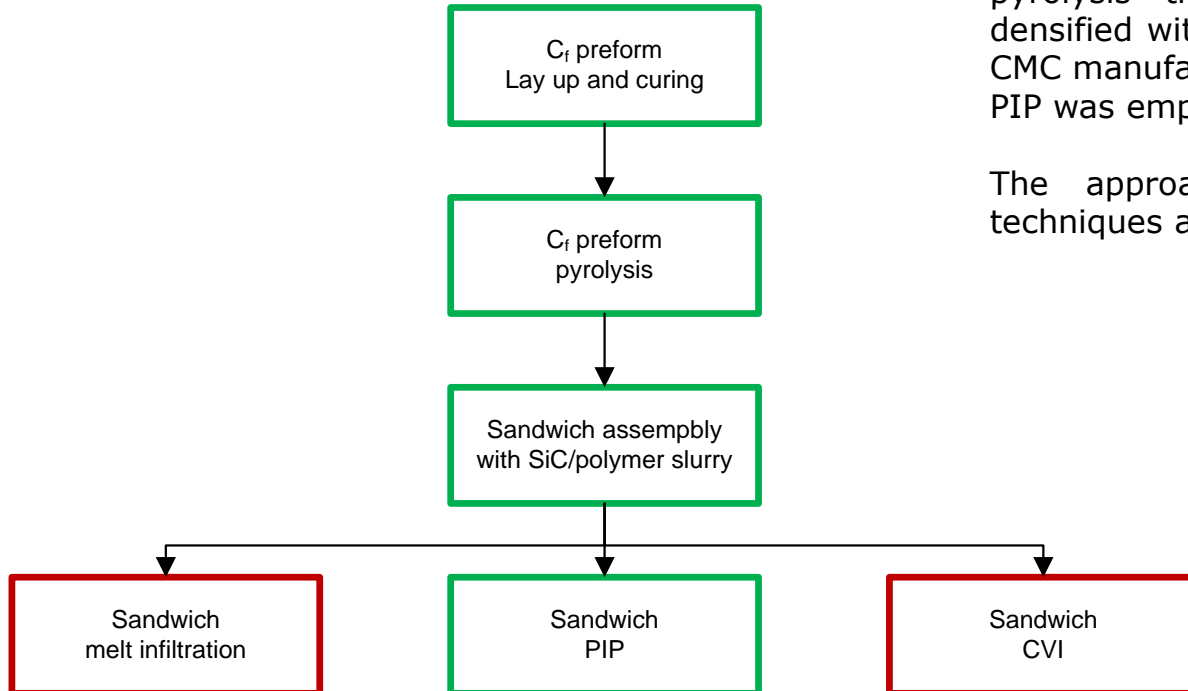


SiC based sandwich structures

This work presents a preliminary study on a **low-cost manufacturing procedure** to assemble ceramic sandwich structures in any shape. After pyrolysis the assembly can be then further densified with the typical techniques employed for CMC manufacturing .

PIP was employed in this work.

The approach is similar to other joining techniques applied for CMC bonding



Krenkel, W; Henke, T; Mason, N Fuentes, M, Martinez Esnaola, JM, Daniel, CMMC 96 , KEY ENGINEERING MATERIALS, 1997, 313-320.

SiC foams



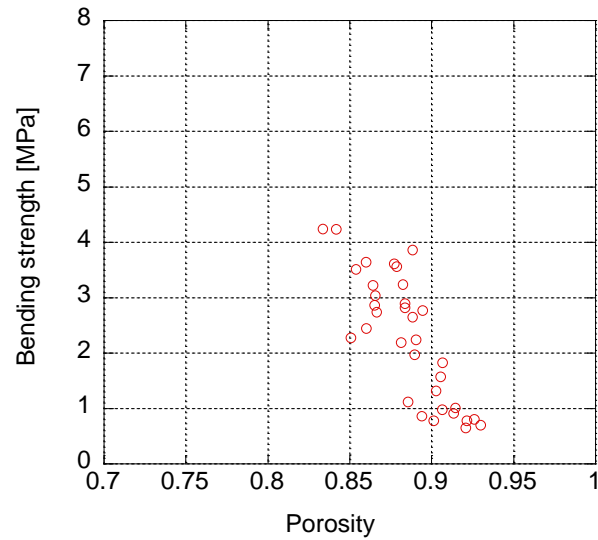
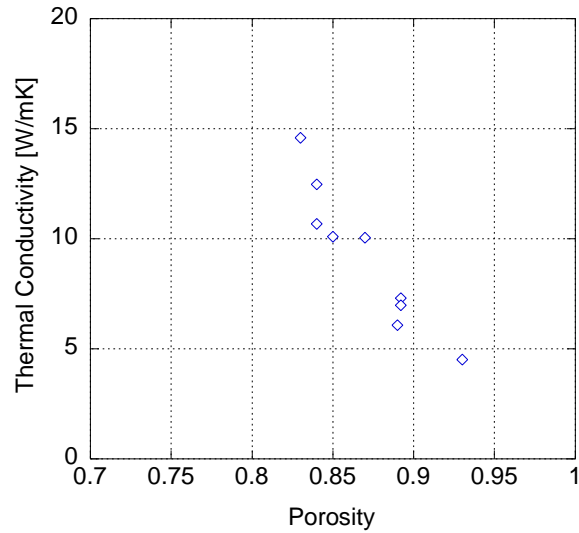
Reticulated SiC foams can bear high thermal loads, high thermal shocks and, due their high porosity ($> 80\%$), they have rather low effective thermal conductivities. If passive oxidation conditions are met they can operate for long time at high temperatures (1400°C) in oxidative environments.

Sample ID	L [cm]	W [cm]	t [cm]	Volume [cm ³]	Mass [g]	Density [g/cm ³]	Por.
ErbisicR	18,5	13,9	1,5	385,72	150,84	0,39	0,86

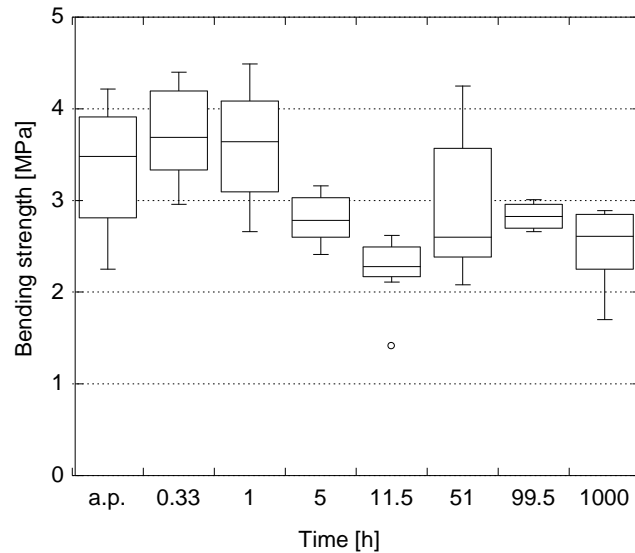
R. A. Mach, F. v. Issendorff, A. Delgado A. Ortona, Advances in Bioceramics and Porous Ceramics: Ceramic Engineering and Science Proceedings, Volume 29, Issue 7, 299-311, 2009, WILEY

Thermal and mechanical properties

Foams physical properties can be controlled changing foam porosity

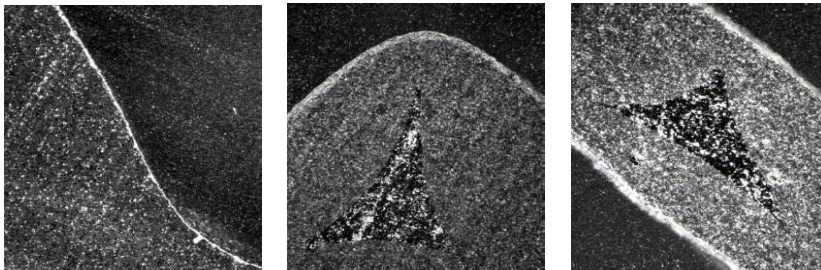


Foams Ageing in porous burners



Power	25 kW
excess air ratio	1.3
Temperature	1400 °C (<i>inferred</i>)
Power ON	10 min
Power OFF	1 min
Ageing	1, 5, 10, 50, 100, 1000 h

The graph shows that **bending strength** decreases during the very first hours of ageing. This is due to the thermal shock imposed to the material during the ON-OFF cycles. After that it **remains almost constant for very longer times** (>> 1000h). That is probably due to the passive oxidation conditions that are met in the burner.



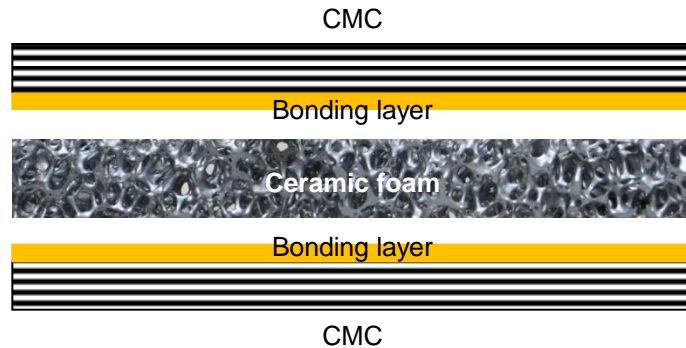
As produced

After 100h

After 1000h

A Ortona; S Pusterla, P Fino; A Mach; A Delgado, S Biamino, Advances in Applied Ceramics, 2010, VOL 109, N° 4, 246-251

Sandwich assembly



The C_f laminate preforms were obtained by laying up four fabrics (200 g/m^2).

After laminates pyrolysis, a slurry (30%w fine SiC powders, 30% w coarse SiC powders, and 40% w Ceraset) was deposited onto one of their faces. Due to the slurry viscosity ($\nu=8100 \text{ m Pas}$) it not fully infiltrated C_f preforms, acting as a thick bonding layer.

The two laminates were placed on the top and the bottom of the foam and cured in the autoclave. Once cured, the sandwich was placed into the furnace and pyrolysed

	Weight [g]	Area [cm ²]	Thickness [cm]	Volume [cm ³]	W_m %	V_f %
C_f Fabrics	20,7	1036	-	-	-	-
Face 1	21,6	259	0,130	33,67	4,35	35,54
Face 2	21,9	259	0,135	34,96	5,80	34,23

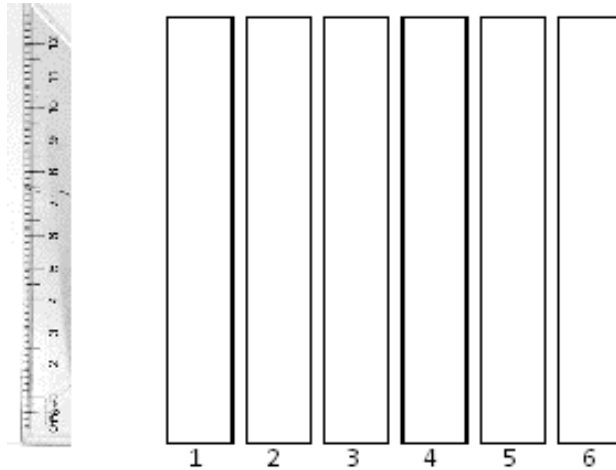
Sandwich PIP

The sandwich faces were densified by infiltration with Ceraset PSZ20 polymeric precursor, performing 5 PIP cycles. Every cycle is based on the following steps.

- Positioning of the panel inside a suitable container
- Tightening of the container
- Applying vacuum up to about 10 mBar of residual pressure
- Fill up with resin the container till covering the sandwich
- Slowly bringing the container to ambient pressure
- Draining excess polymer.

		Face 1	Face 2	Core	Sandwich
Pre forming	Preform curing	21,6	21,9	150,84	194,34
	Preform pyrolysis	21,09	20,76		192,69
	Sandwich assembly	43,92	43,96		281,72
	Sandwich pyrolysis				236,00
Densification	PIP 1				252,7
	PIP 2				275,2
	PIP 3				287,7
	PIP 4				288,6
	PIP 5				293,7

Bending tests



The sandwich panel was cut with a diamond saw in 6 pieces ($139 \times 25 \times 18.6 \text{ mm}^3$). During cutting, the bottom face of samples 3, 4, 5, 6 deboned from the ceramic core, samples 1, 2 remained bonded.

Three point bending tests were performed with an universal testing machine (Zwick/Roell Z050 Germany) using a span of 100 mm. Sample dimensions were chosen ($139 \times 25 \times 18.6 \text{ mm}^3$) to compare data with previous works. Cross head speed was 0.01 mm/s. To evaluate the influence of the face-to-core bonding on the overall mechanical behaviour, bonded samples (Sandwich 1-2) and debonded samples (Sandwich 5,6) were tested. All the samples were tested with the same orientation: the bottom face (the one which has deboned in samples 5 and 6) against the bottom supports



Foam sandwich, unloaded

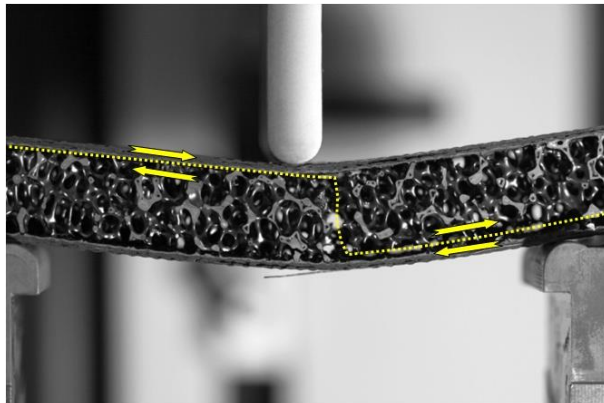
A Ortona; S Pusterla, P Fino; A Mach; A Delgado, S Biamino, *Advances in Applied Ceramics*, 2010, VOL 109, N° 4, 246-251

Toughness

In both bonded and debonded sandwiches, foam broke first vertically at the centre, below the upper ram, then cracks propagated horizontally at the bonding-foam interface. During this phenomenon several broken struts were observed, some were torn off the bonding layer, some broke inside the foam. No delaminations between the bonding layer and the CMC were observed.

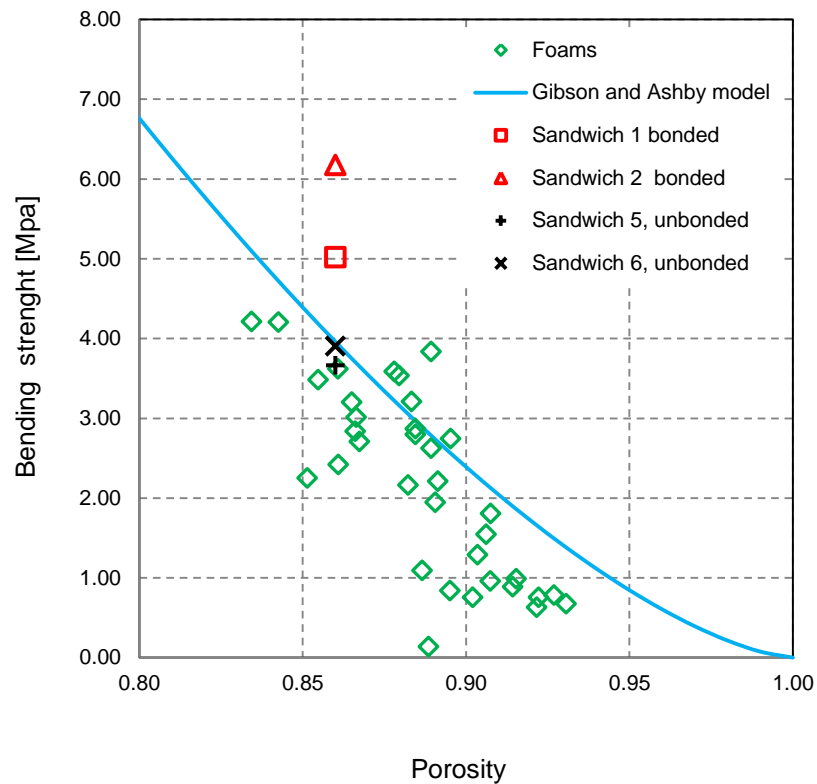


Foam sandwich, unloaded



Foam sandwich, loaded

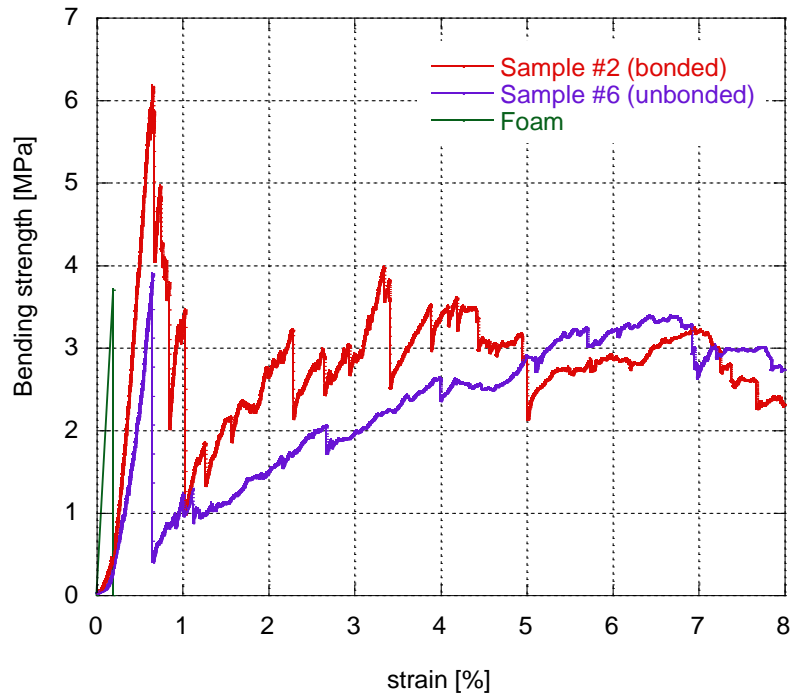
Bending tests results



Three point bending strength of de-bonded sandwiches is equivalent to that of plain foams, and to analytical data (calculated from the Gibson and Ashby model).

Bonded foams show a bending strength increase (36-67%)

Bending tests results

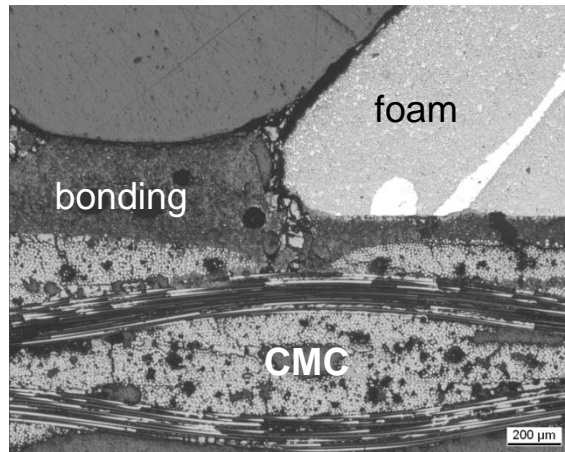


De-bonded samples showed a similar maximum strength to that of a plain foams with similar densities. **After foam failure, the sandwich was still bearing loads**, thanks to the attrition between the sliding broken foam and its mate CMC face. Since the CMC faces were loaded well below their failure strength, they did not break.

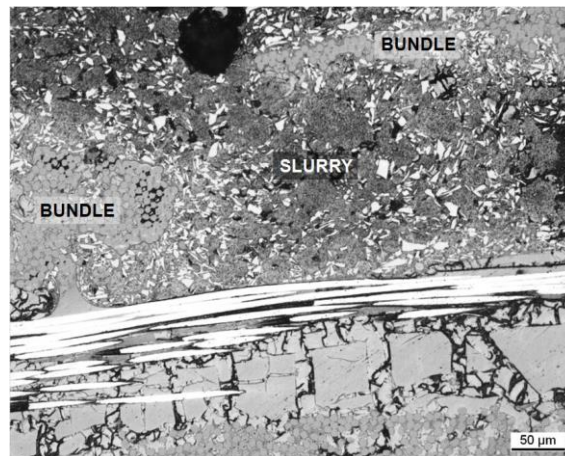
CMC to core bonding

As a result of the described manufacturing procedure, the bonding layer wraps the struts on the foam side and, on the CMC side, infiltrates the bundles of its external laminate and some fibres within these bundles.

Struts embedding into the bonding layer effectively works as a joint between the CMC and the foam. The better the struts are embedded into the slurry the more CMC and foam are fastened.



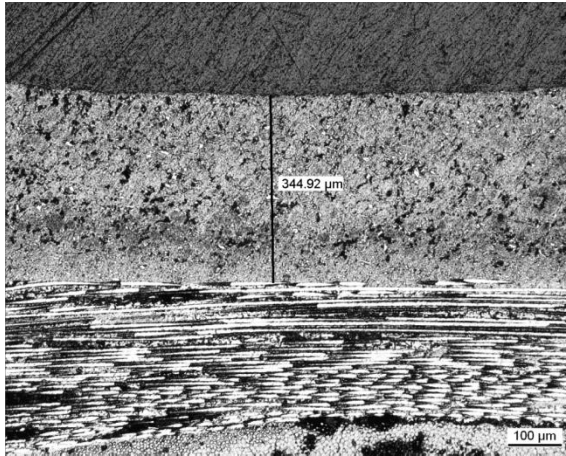
Bonding, foam side



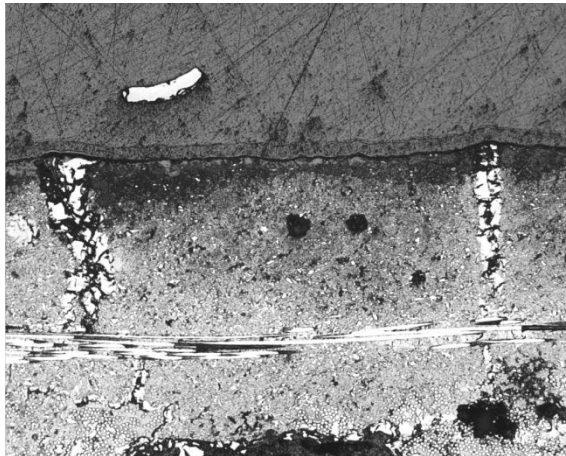
Bonding, CMC side

Bonding layer

The bonding layer must have a thickness of few hundreds of μm in order to wrap the foams struts. Due to the shrinking it presents some cracks which are filled by following PIP cycles



Bonding thickness



Shrinking after 1st pyrolysis and re-impregnation

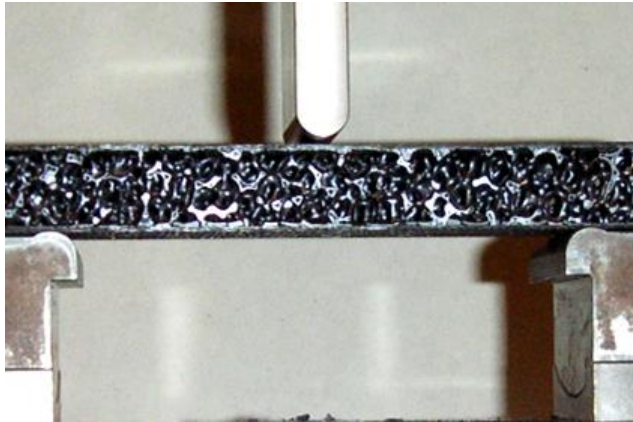
Conclusions

- Struts embedding into the bonding layer effectively works as a joint between the CMC and the foam.
- In these sandwiches, **load is transferred** from the faces to the core, not by adhesion but, **by mechanical joining.**
- foam milling is fundamental to have the maximum number of struts in contact with the CMC.
- Foams and CMC must have similar coefficient of thermal expansion,

other samples were prepared with more and less porous foams.

- The more porous foams broke inside during PIP cycles.
- The less porous foams broke at the bonding interphase

SiC_f-SiC_m CMC and SiC core



Foam sandwich, unloaded

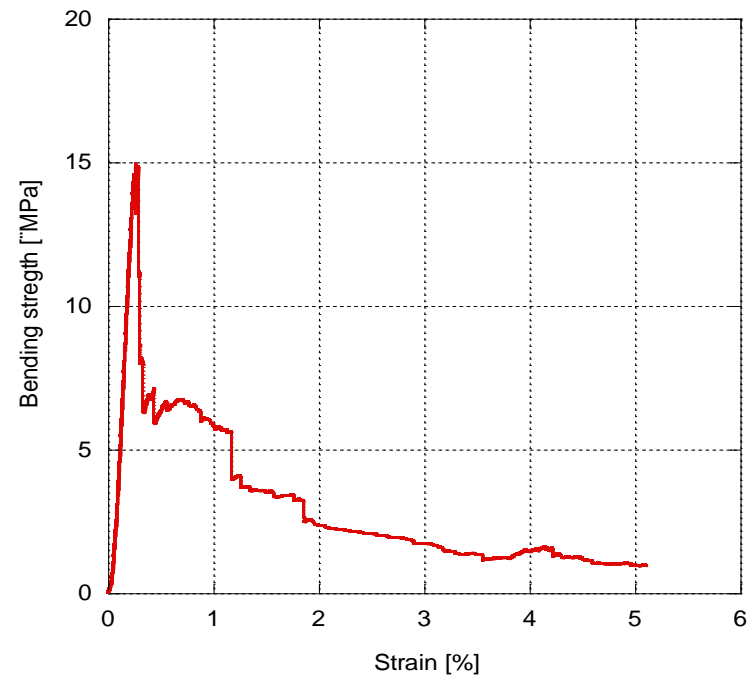


Foam sandwich, loaded

In order to eliminate the thermal expansion mismatch between faces and core a new sandwich was prepared with SiC fibers Tyranno LOXM (from UBE) without interphase.

Debonding was not observed during processing and cutting.

Bending tests were performed with increased bending strengths



Acknowledgments

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Ing. Giovanni Bianchi

simulation

ceramic foams

composites

experiments set up

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