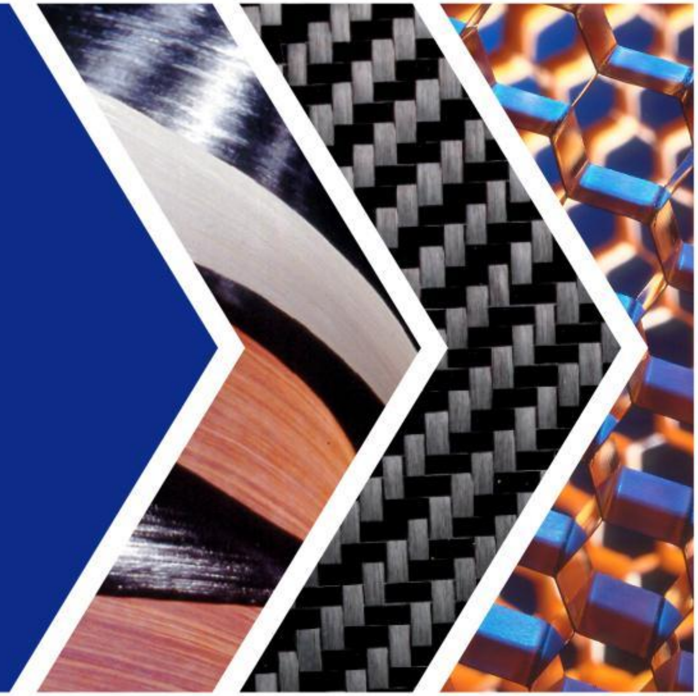
Multi-layer carbon stacks for large wind turbine rotor blades

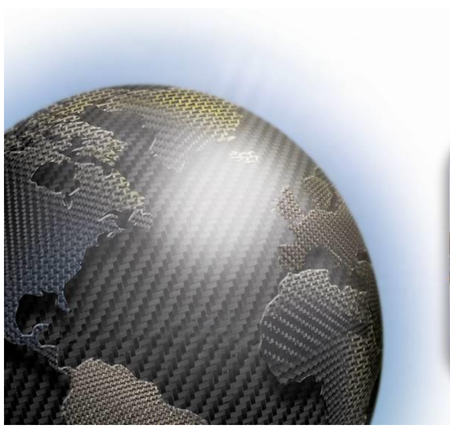


Joerg Radanitsch

16 October 2014 – theCAMX.org

Hexcel Company Profile

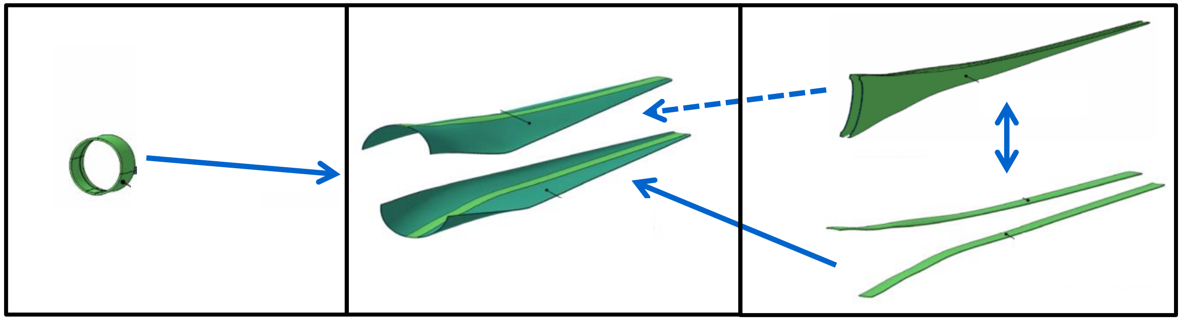
- Technology leader in advanced composites
- Serving commercial aerospace, space & defense and industrial
- Net Sales 2013: $1.68 Billion
- 5,300 employees worldwide
- 19 manufacturing sites (including JV in Malaysia)
- Headquarters in Stamford, CT, USA
- Listed on New York and Paris Stock Exchanges



HEXCEL®

Hexcel in Wind Energy

- **Market Leader for prepreg materials in Wind Energy**
  - Annual capacity of > 20 000 t
  - Global Supplier for over 20 years; Production sites in USA, China, Europe
  - Product development in close cooperation with key accounts; Technical Support and R&T
- **Carbon materials for load carrying structures in large wind turbine rotor blades**
  - Cured Laminates and Prepregs for spar caps or reinforced shells

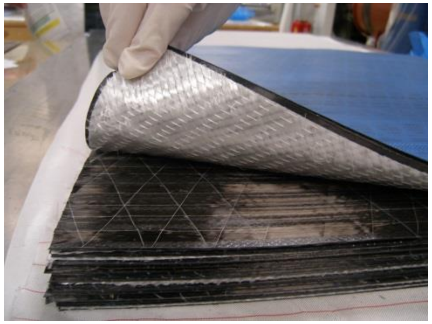


Carbon sheet materials for spar caps

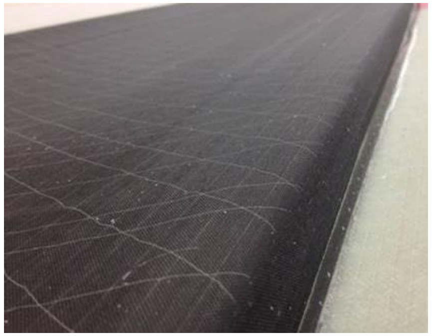
Multi-layer approach for spar caps

Making use of individual ply functions of the following materials

- **HexPly® Carbon UD Prepreg – 600 gsm + grid**
  - 2 layer material
  - **air-vent**; **UD reinforcement and bonding** function



- **Polyspeed® Carbon UD Laminate – 600 gsm**
  - **Pre-cured UD reinforcement; exo control**, **caul plate** function



- **HexFIT® Glass Biax Semipreg – 600 gsm +/- 45**
  - **air-vent; +/- 45 reinforcement and bonding** function

Take advantage of individual ply functions

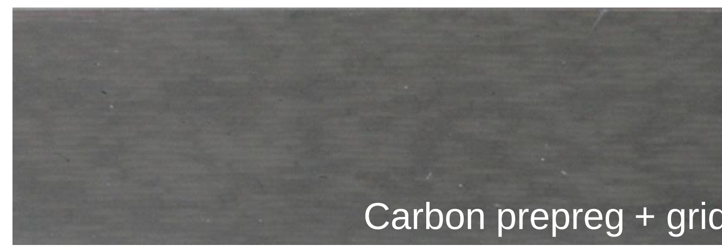
The air-vent function

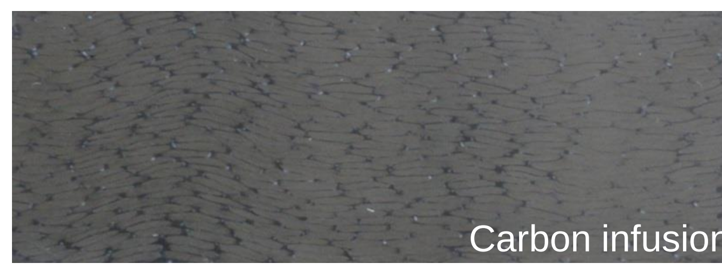
Morphological comparison of multi-layer prepreg stacks and infusion part

- **Homogeneous** fiber area weight
- Low ply waviness
- Porosity in Biax +/-45°

- Very **uniform fiber/matrix distribution**
- Low porosity due to grid layer

- Good air-vent
- **resin rich domains** at infusion channels
- some 90° waviness

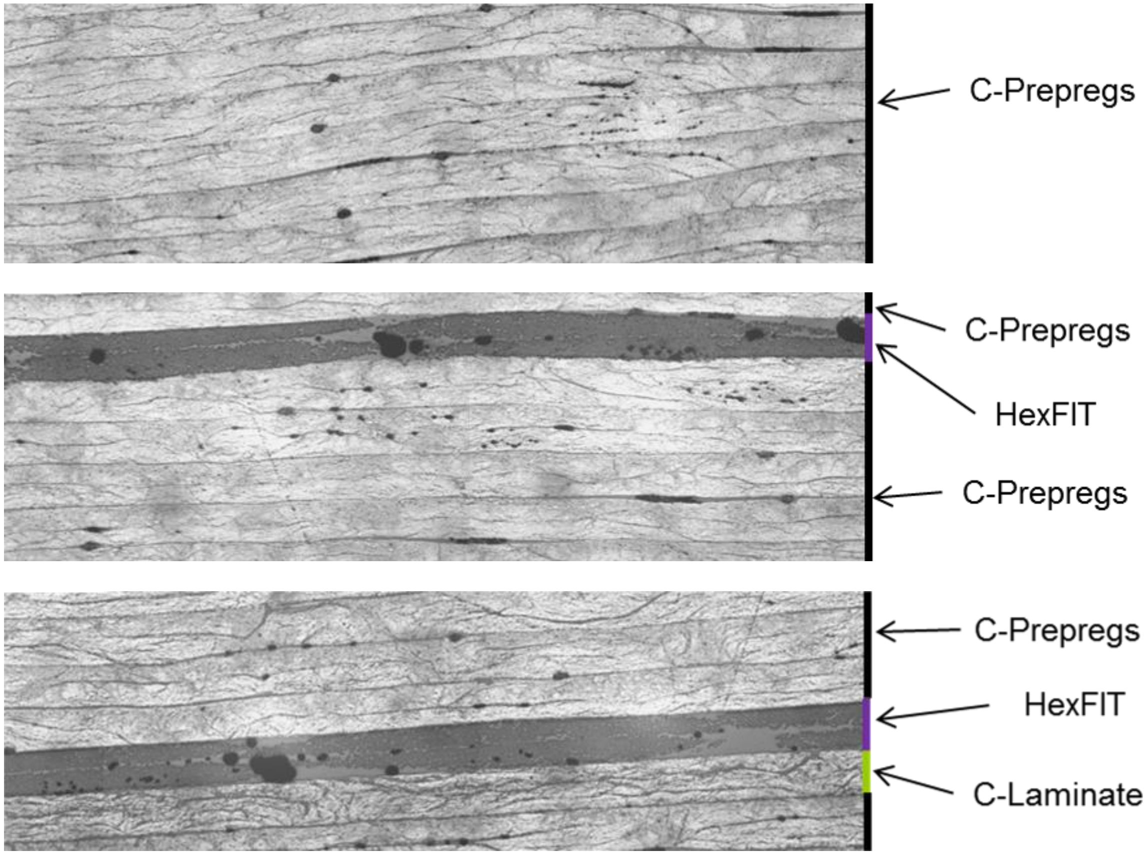




Prepreg part shows monolithic part character

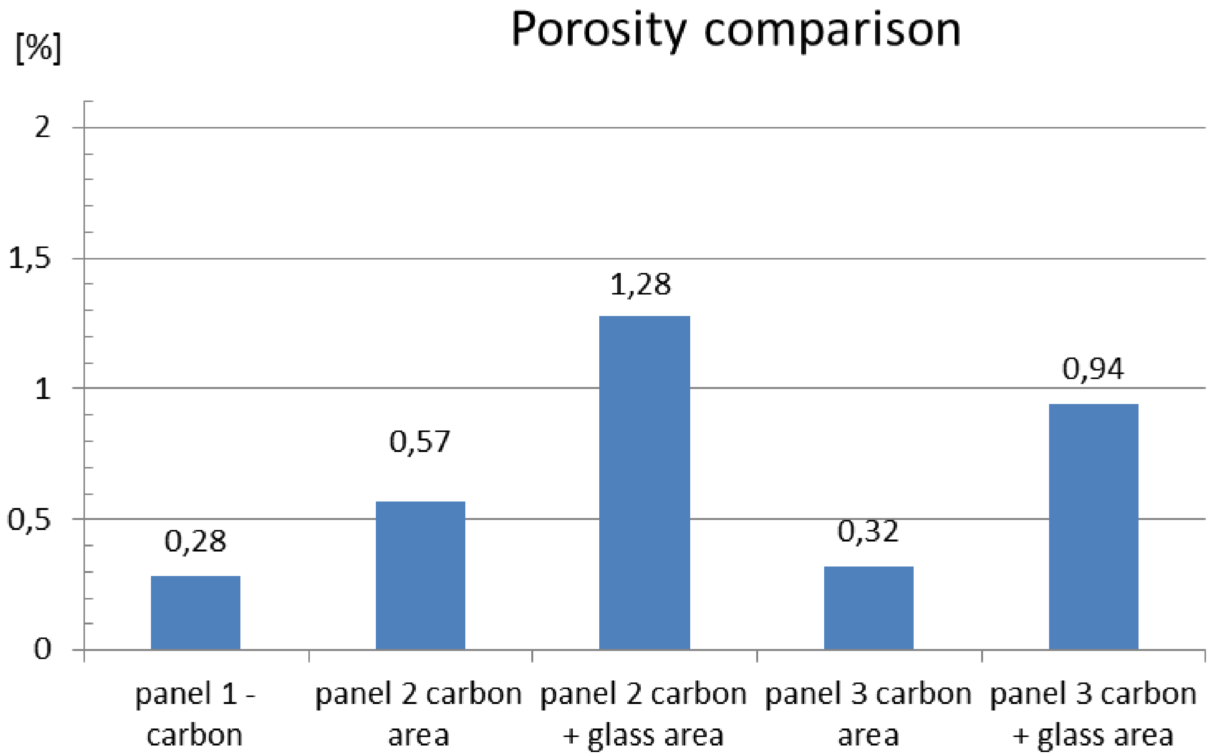
Multi-layer build on a micro scale

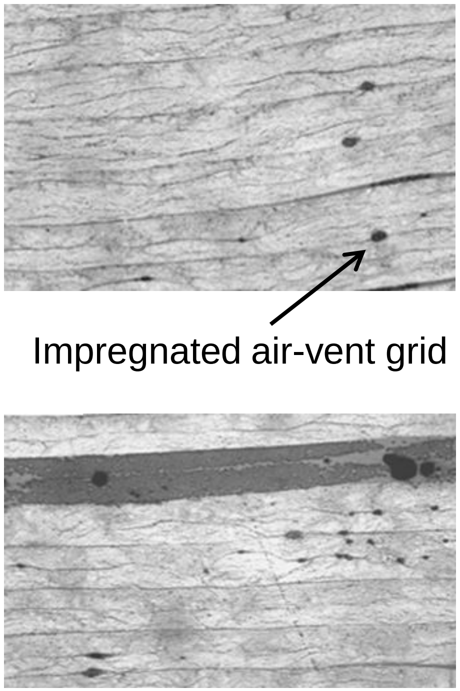
- **Layup 1**
  - Carbon UD Prepreg + grid
- **Layup 2**
  - Biax prone to entrap air at fiber crossings
- **Layup 3**
  - Polyspeed® Carbon UD Laminate to flatten a stack, caul plate function



Carbon laminate to increase process robustness and quality

Porosity of different part sections

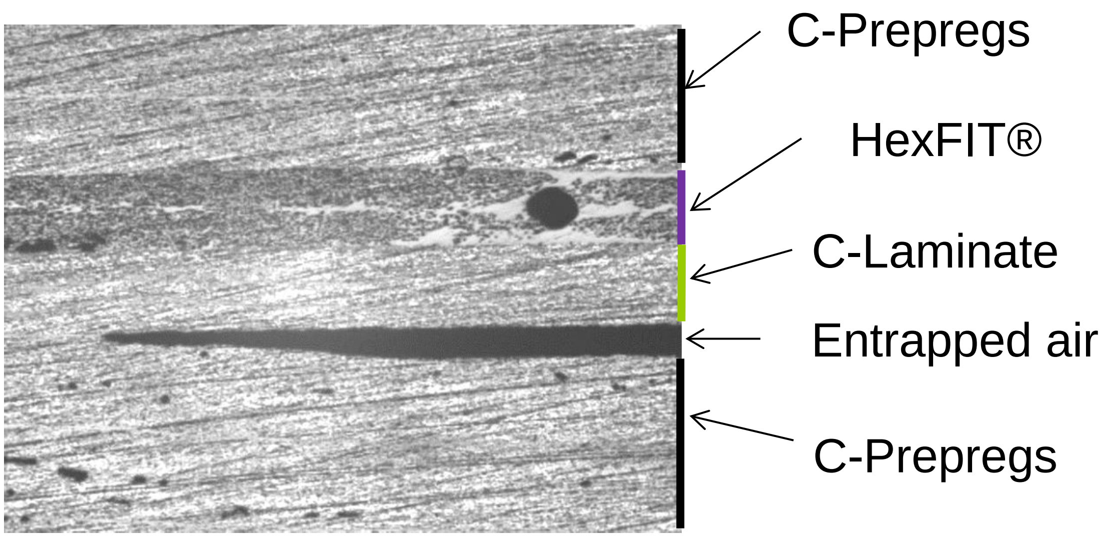




Porosity in carbon areas is very low due to air-vent grid layer

Multi-layer performance

- Wrong stack sequence leading to defects



- Example: The absence of air vent scrim on C-Laminate / C-Prepreg interface leads to entrapped air.

Stack sequence is key for multi-layer build

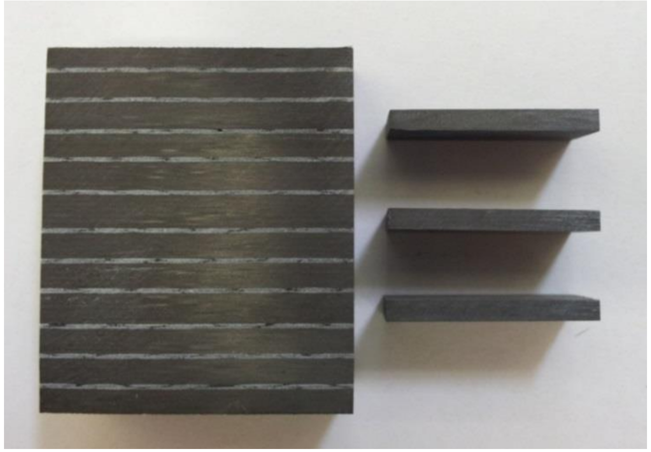
Carbon multi-layer – interfaces by ILSS

- **Pure prepreg vs. alternating specimen build with pre-cured C-laminate**

test	layup	no. layers	product	direction	sequence	result
ILSS	C-Prepreg	4	UD600	0°	PPPP	70 MPa
ILSS	alternating	4	UD600+Polyspeed	0°	PPPL	68 MPa
ILSS	alternating	4	UD600+Polyspeed	0°	PLPL	61 MPa
ILSS	Block cut	-	UD600+Polyspeed	0°	PPPL	78 MPa

L…Laminate
P…Prepreg

- 4 ply Prepreg - ILSS: **70 MPa**
- 4 ply Prepreg & pre-cured - ILSS: **68 MPa**
- "Block cut" specimens, 2,4 mm - ILSS: **78 Mpa**



Highest ILSS for multi-layer material

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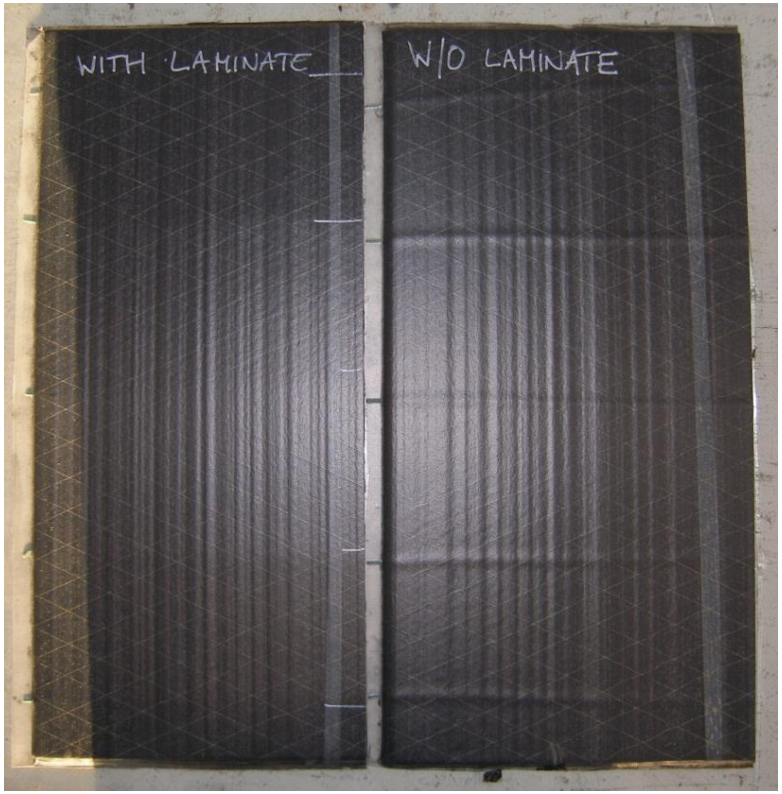
Polyspeed® - function as caul plate I

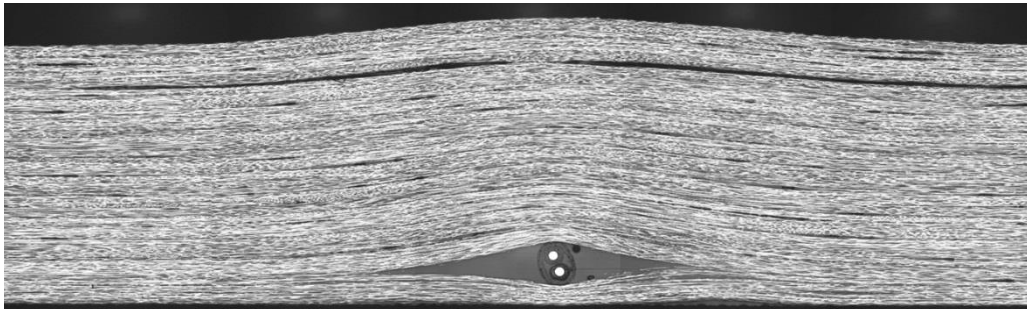
Left: C-laminate reduces defect size **Right: no C-laminate, defect visible**



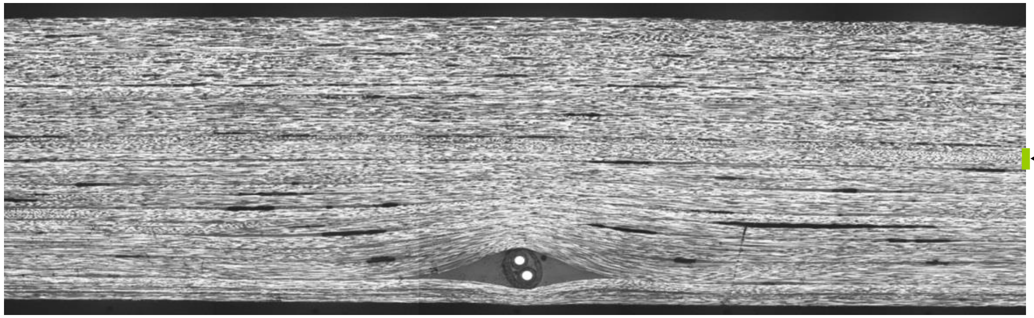
Wire test to display caul plate function

Polyspeed® - function as caul plate II

- A distortion (wire) in 90° direction causes a wavy prepreg stack.



- Introducing Polyspeed® pre-cured carbon UD laminate, waves are totally smoothened. Polyspeed ® functions as a build in caul plate

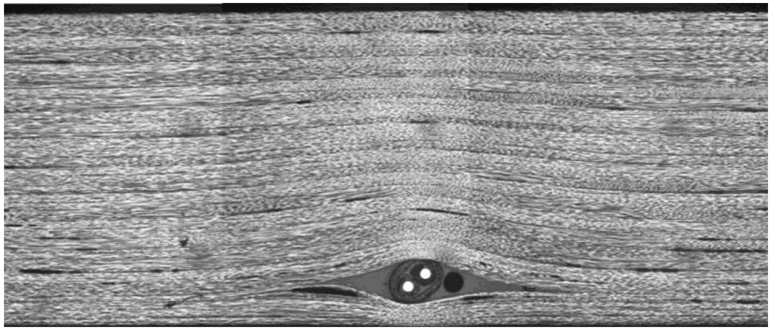


Polyspeed layer

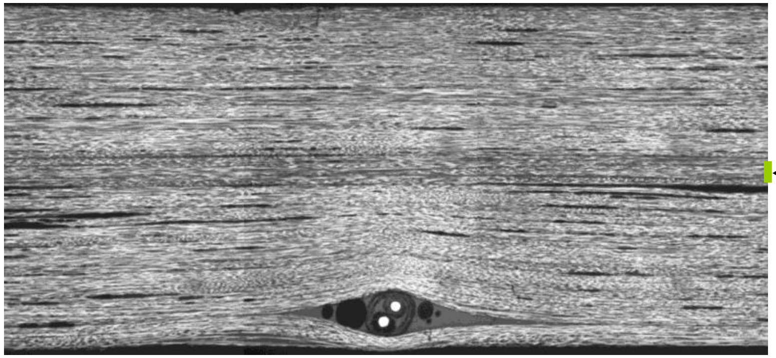
Polyspeed reduces defect area and increases performance

Polyspeed® - function as caul plate III

- Caul plate on top of the prepreg stack leads to plane surface, waves are present throughout the entire specimen cross section.



- Caul plate on top and C-laminate inside, waves are stopped at C-laminate.



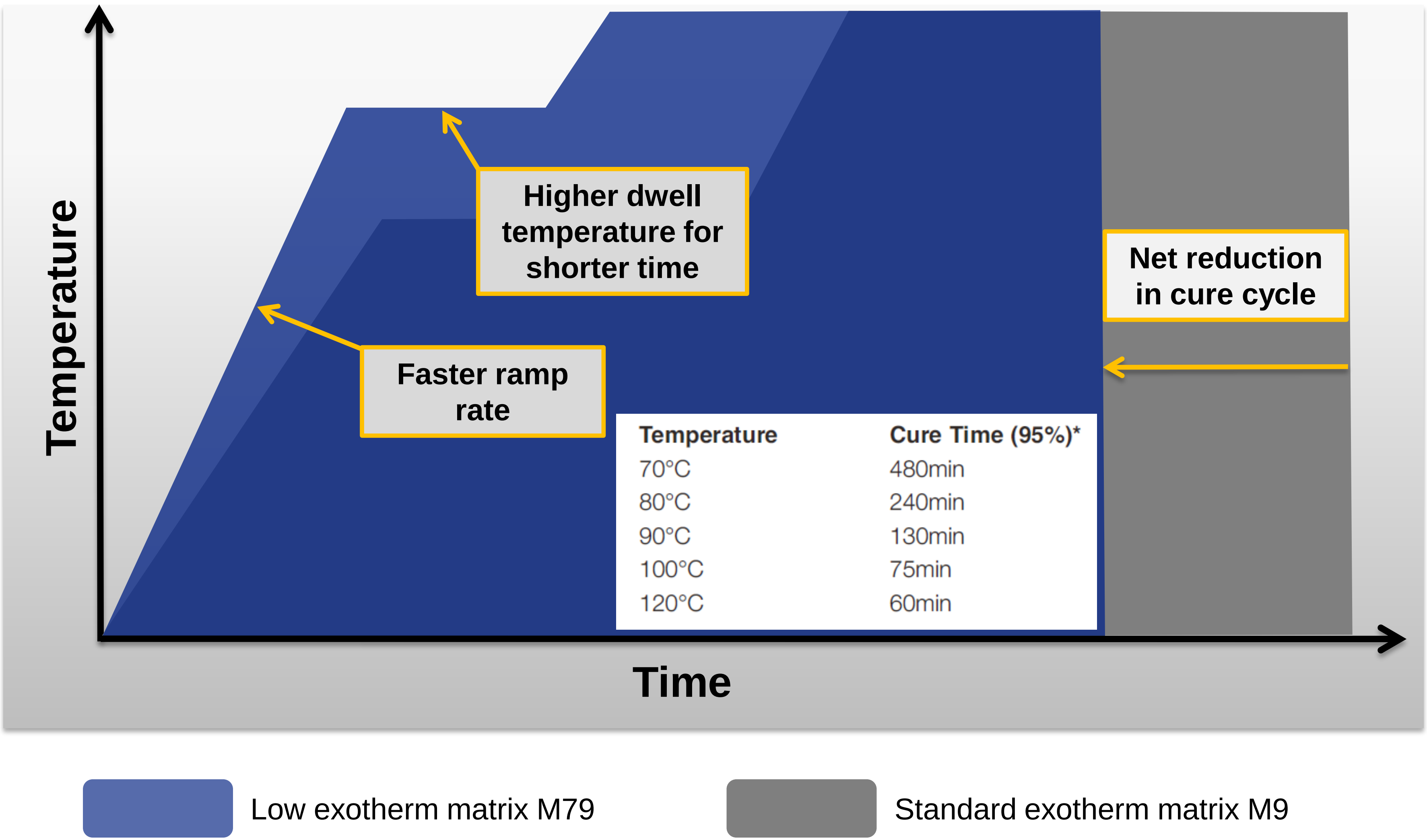
Polyspeed layer

Laminate improves fiber alignment in carbon spar caps

Carbon cube experiment

Introducing M79 - Low exotherm & low temperature cure epoxy resin to multi-layer concept

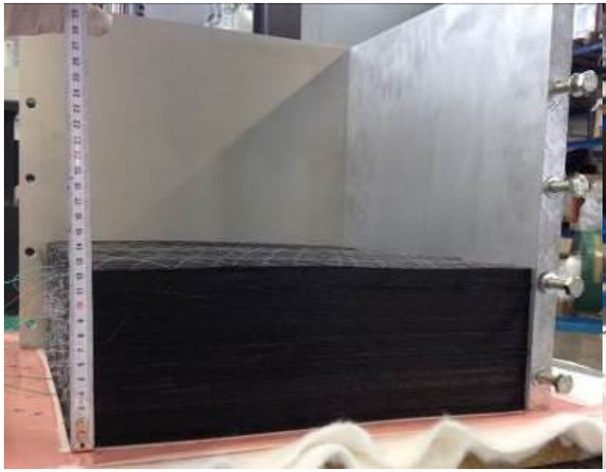
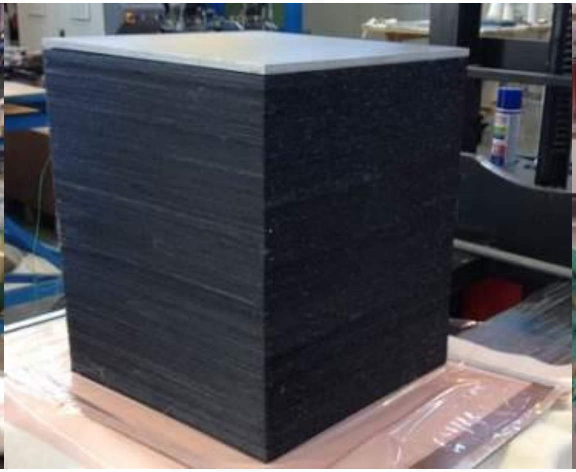
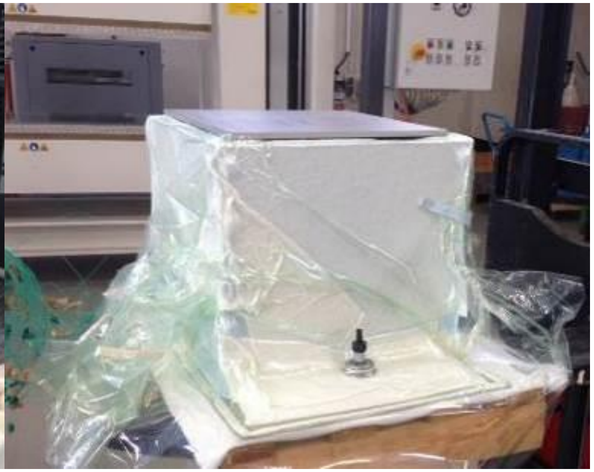
The Value of Low Exotherm in Thick Parts



Temperature	Cure Time (95%)*
70°C	480min
80°C	240min
90°C	130min
100°C	75min
120°C	60min

Carbon cube experiment - layout

- Low exotherm resin in a very thick carbon part dimensions 400 x 400 x 400 mm, **bejond existing applications**
- Material: M79 UD **600 gsm prepreg** with **air-vent grid** layer
- **695 plies** of HexPly® M79 carbon fiber prepreg
- Layup in tool (4 sides); cured in vacuum bag and press (top / bottom)

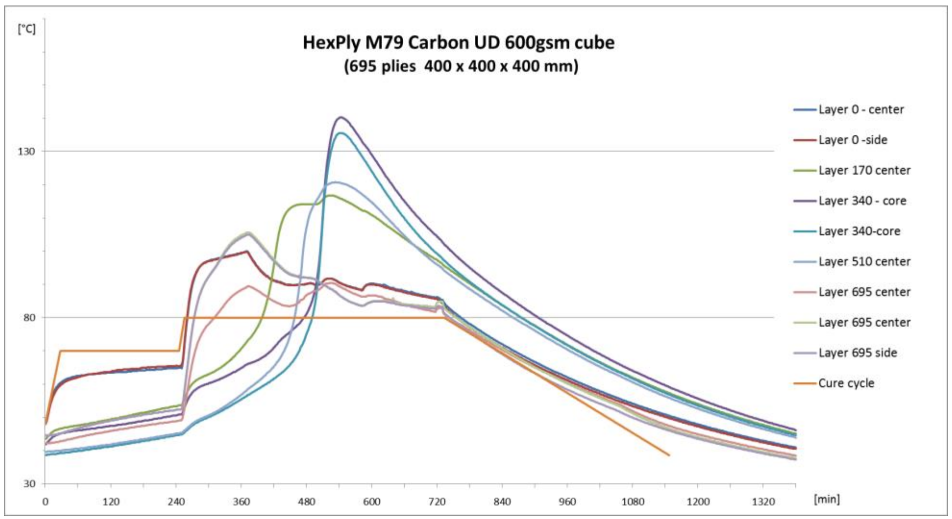




Easy layup process of the 695 prepreg plies

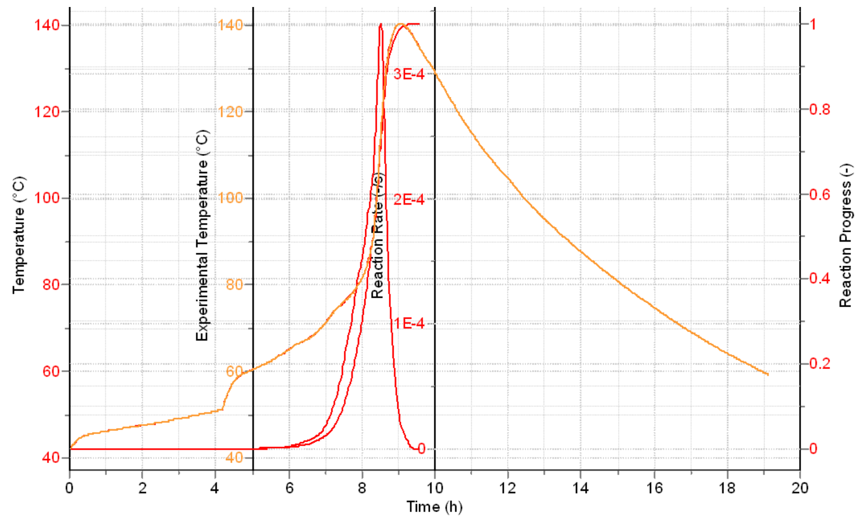
Carbon cube experiment – results I

Results after cure

- T_{max} exo < 140 °C (center); $T_{surface}$ < 90 °C
- Once at 80°C, cure took 6 hours only
- All parts of the cube fully cured (calc.)



cure temperatures

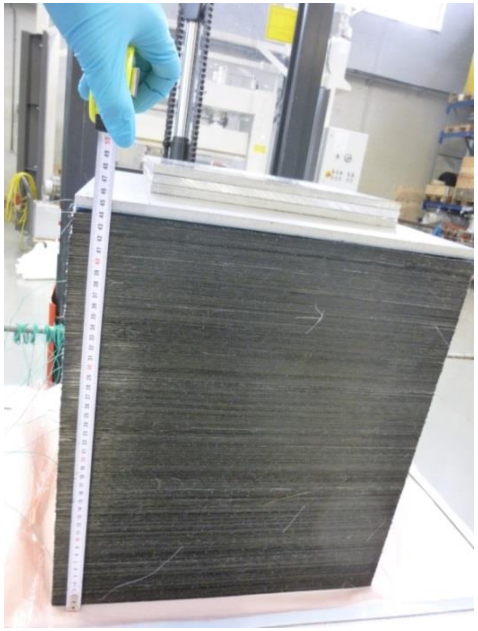


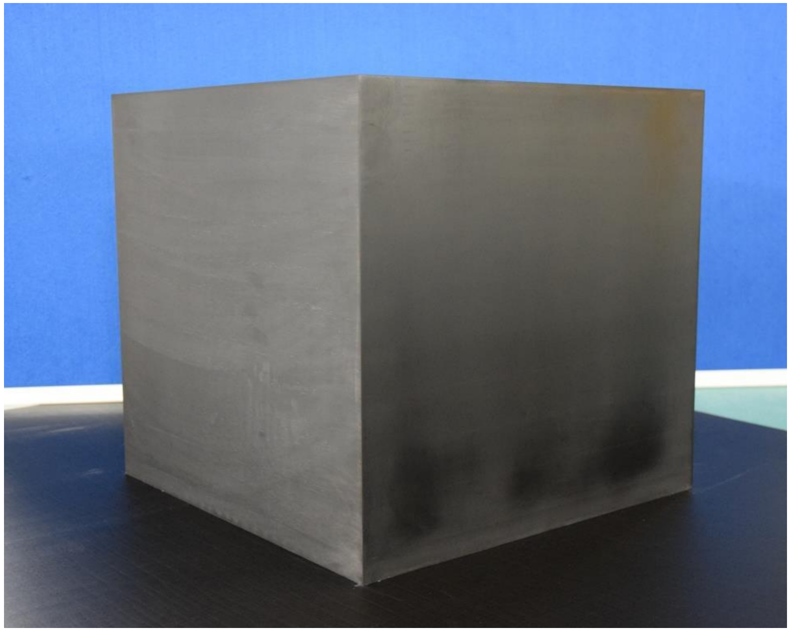
calculated reaction progress & reaction rate

Controlled exotherm and fully cured part

Carbon cube experiment – results II

- The very low exotherm (100 - 120 J/g) of M79 enables to cure thick sections at moderate temperatures
- Multi-layering of carbon prepreg with air-vent layers for easy processing and close to monolithic part character





You can see the cube on Hexcel´s booth at CAMX

Thank you!

Joerg Radanitsch - CAMX 2014

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