Recent Developments in Materials and Processes for Blades at Hexcel

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Sandia Wind Turbine Blade Workshop 2012

Agenda

- **Introduction**
- **Prepreg resin systems for wind energy**
- **Prepregs for the surface**
- **Prepregs for thick load-carrying structures**
  - Effect of architecture on porosity
- **Use of prepregs for construction of spar caps**
  - Conventional, pre-cured
  - New: co-infused and co-cured
- **Conclusions**

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Introduction to Hexcel

The company
Hexcel in wind energy

Company Profile

- **Leading global provider of advanced composites**
- **Technology leader with largest portfolio of qualifications**
- **Primary markets: commercial aerospace, space & defense and industrial**
- **Net Sales of $1,392.4 million in 2011**
- **Approximately 4,000 employees worldwide**
- **18 production sites (including JV in Malaysia)**
- **Headquarters in Stamford, CT, USA**
- **Listed on NYSE**

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Hexcel in Global Wind Energy

- **Market Leader for prepreg materials in Wind Energy**
- **Annual capacity of >20 000t**
- **Over 20 years experience**
- **Global Supply, Sales, Technical Support and R&T**
- **Product development in close cooperation with key accounts**

Plant for wind energy at Windsor Colorado, opened in 2009
(Other dedicated plants in Austria and in Tianjin, China)

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Prepreg resin systems for wind energy

Current resin systems
Systems for low exotherm
Next generation systems

Typical Prepreg Systems in Wind Energy

Resin systems

M9G	**310 J/g**
M9GF	**230 J/g**
M19G	**160 J/g**

UD Products

Carbon 500-600 gsm

Glass 1000-3000 gsm

Storage	
Temperature	Shelf life
+23°C	6 weeks
+5°C	6 months
-18°C	18 months

Overall cure cycles

~4 to ~8 hours (optimisation is key)

Typical prepregs:
high areal weights + full impregnation + low reaction enthalpy

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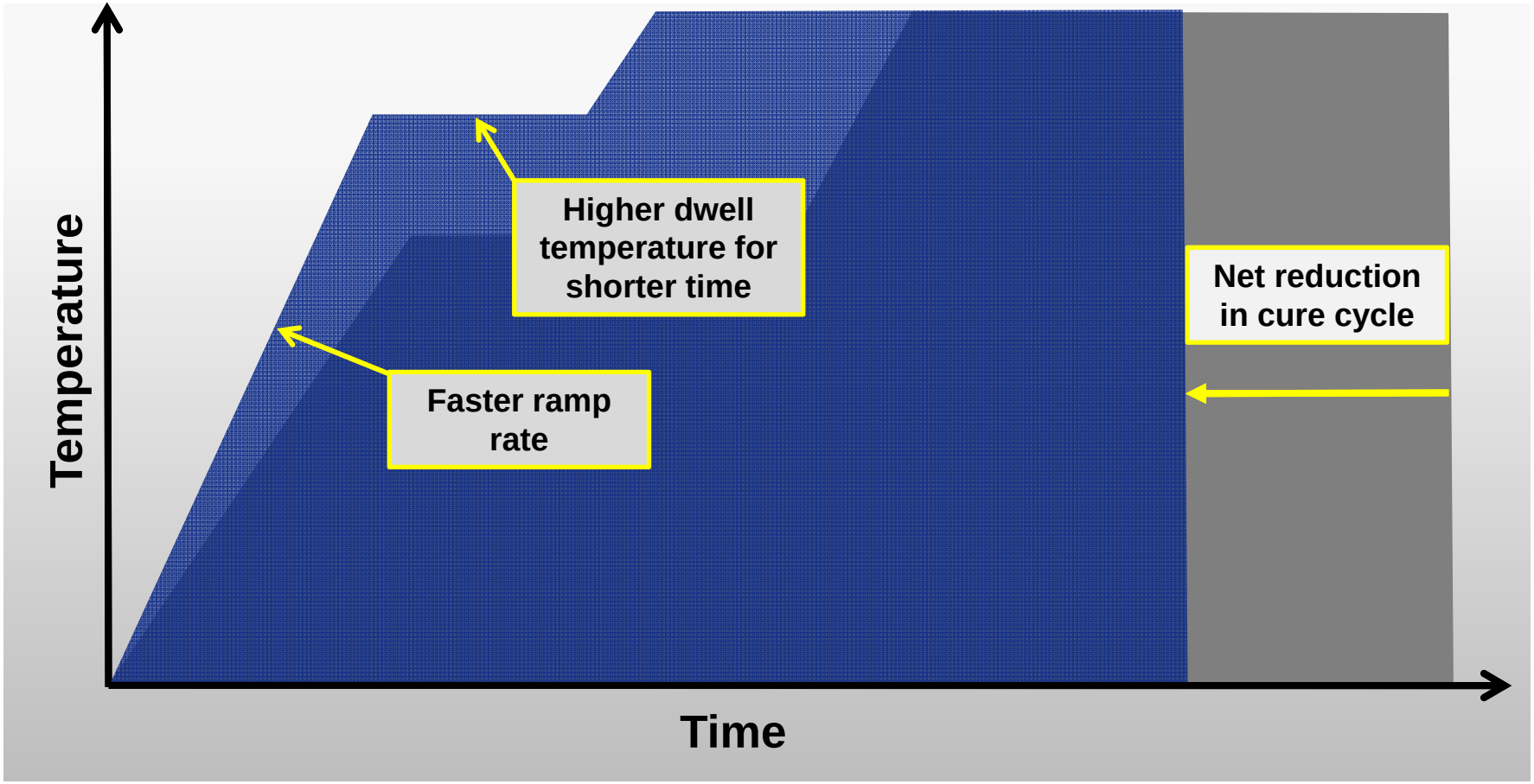
The Value of Low Exotherm in Thick Laminates



Low exotherm matrix e.g. M19G

Standard exotherm matrix e.g. M9G

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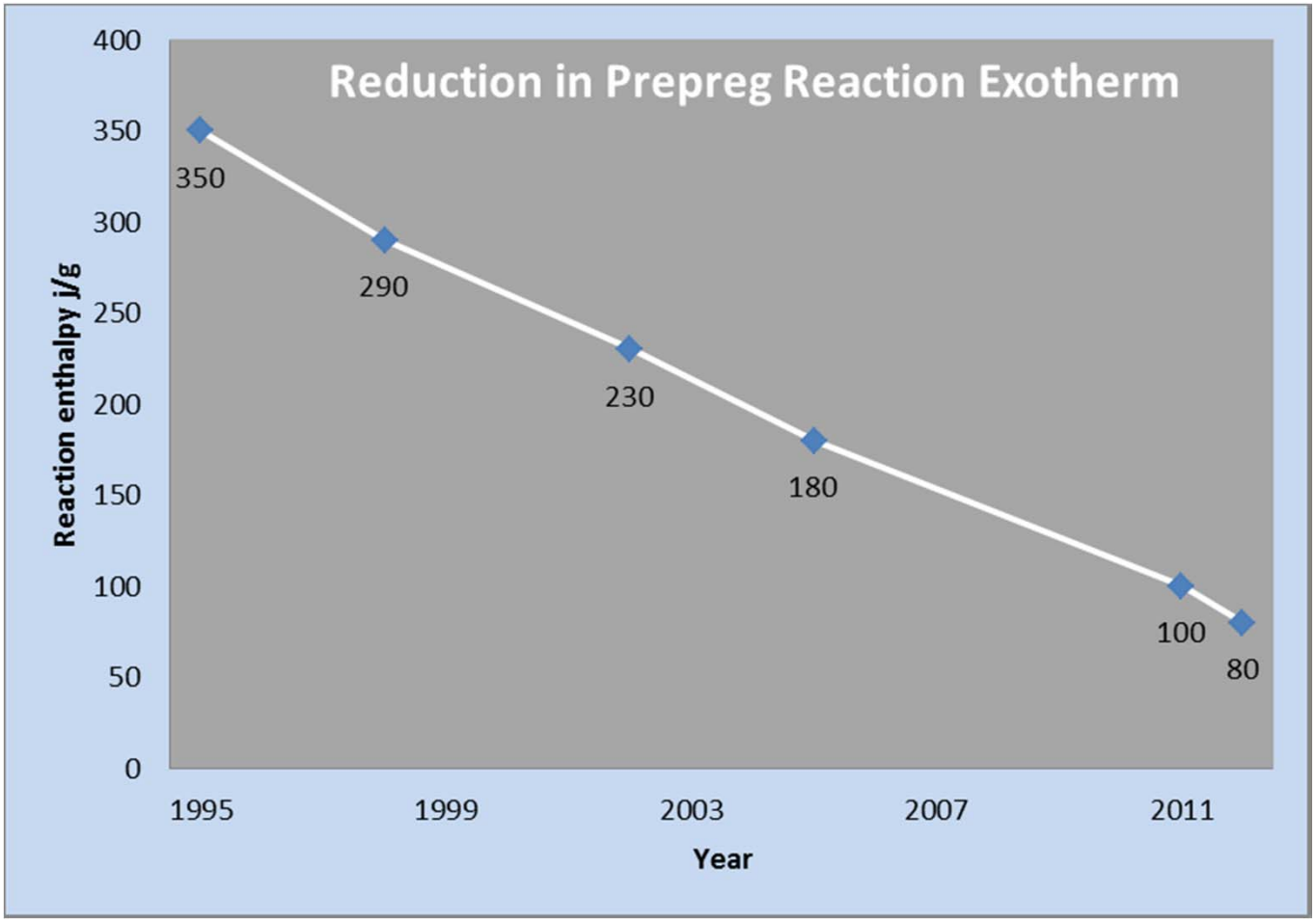
The Trend to Lower Exotherm, 1995-2012



Latest prepreg matrices minimise reaction exotherm allowing short cure cycles of thick structures

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Next Generation Resin Systems

An improved (prepreg) matrix should have the following properties:

- Low cure temperature
- Fast cure
- Long outlife
- Low exotherm
- Superior static and dynamic mechanical properties
- Low cost

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Next Generation Resin Systems

Recent developments have yielded the following

- Cure: 70°C ~10 hrs; 80°C ~6 hrs; 120°C <1 hr
- Outlife > 2 months
- Exotherm ~100 j/g
- Static mechanical properties as M9G
- Dynamic mechanical properties under evaluation
- Product form as current prepregs/ semipregs
- As easily manufactured as current M9G family prepregs

Provisional data

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Prepregs for the Surface

Prepregs for the Shell Surface

Shell prepregs are used for the aerodynamic shell

- Gel coats may be used to provide a good paint-ready surface
- Polyurethane paints may be used for the final surface

This process can be simplified by using specific shell prepregs

e.g. Products such as XF2P

- Build the aerodynamic shell surface
- Eliminate the gel coat

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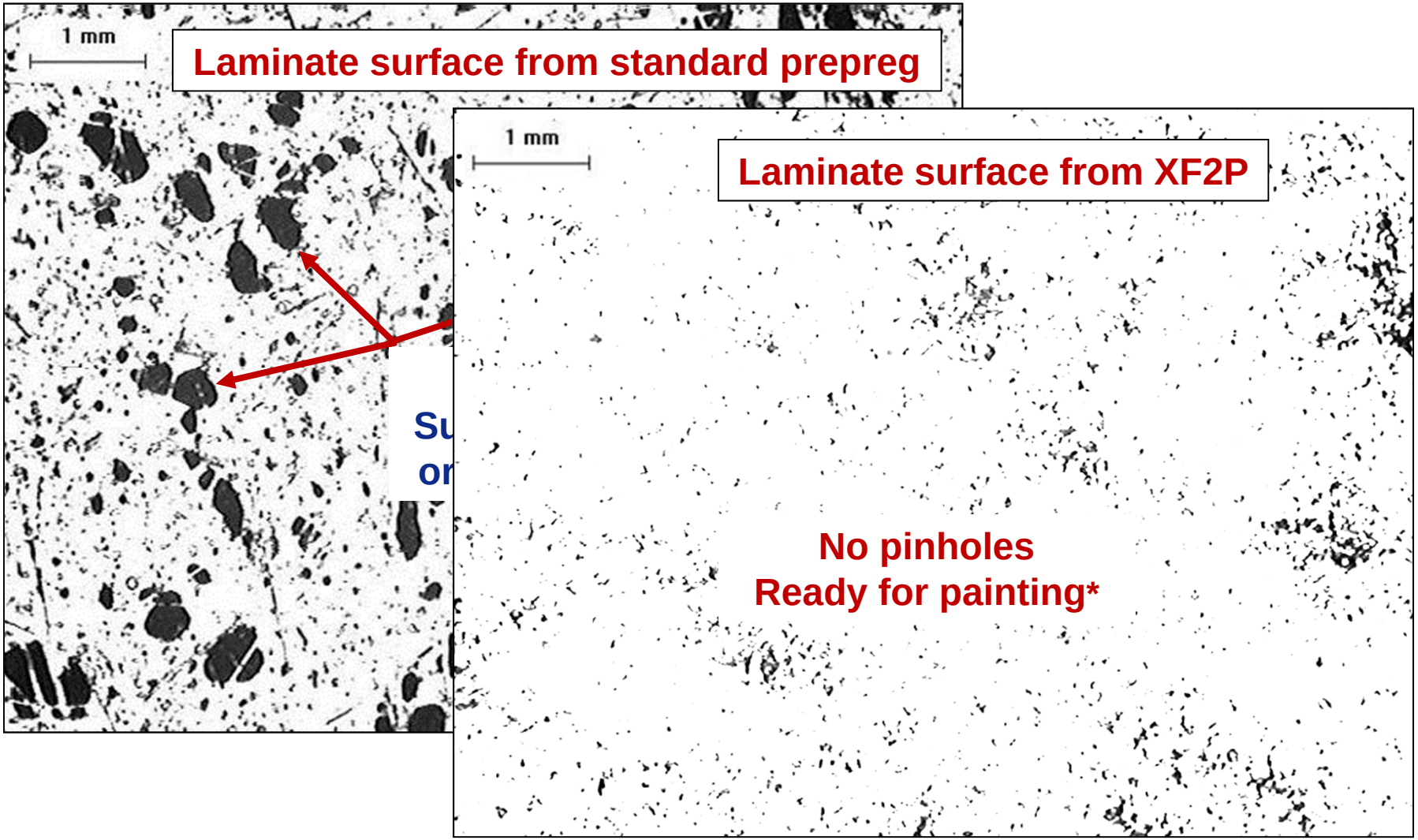
XF2P: Surface Characterisation



* After removal of release agent

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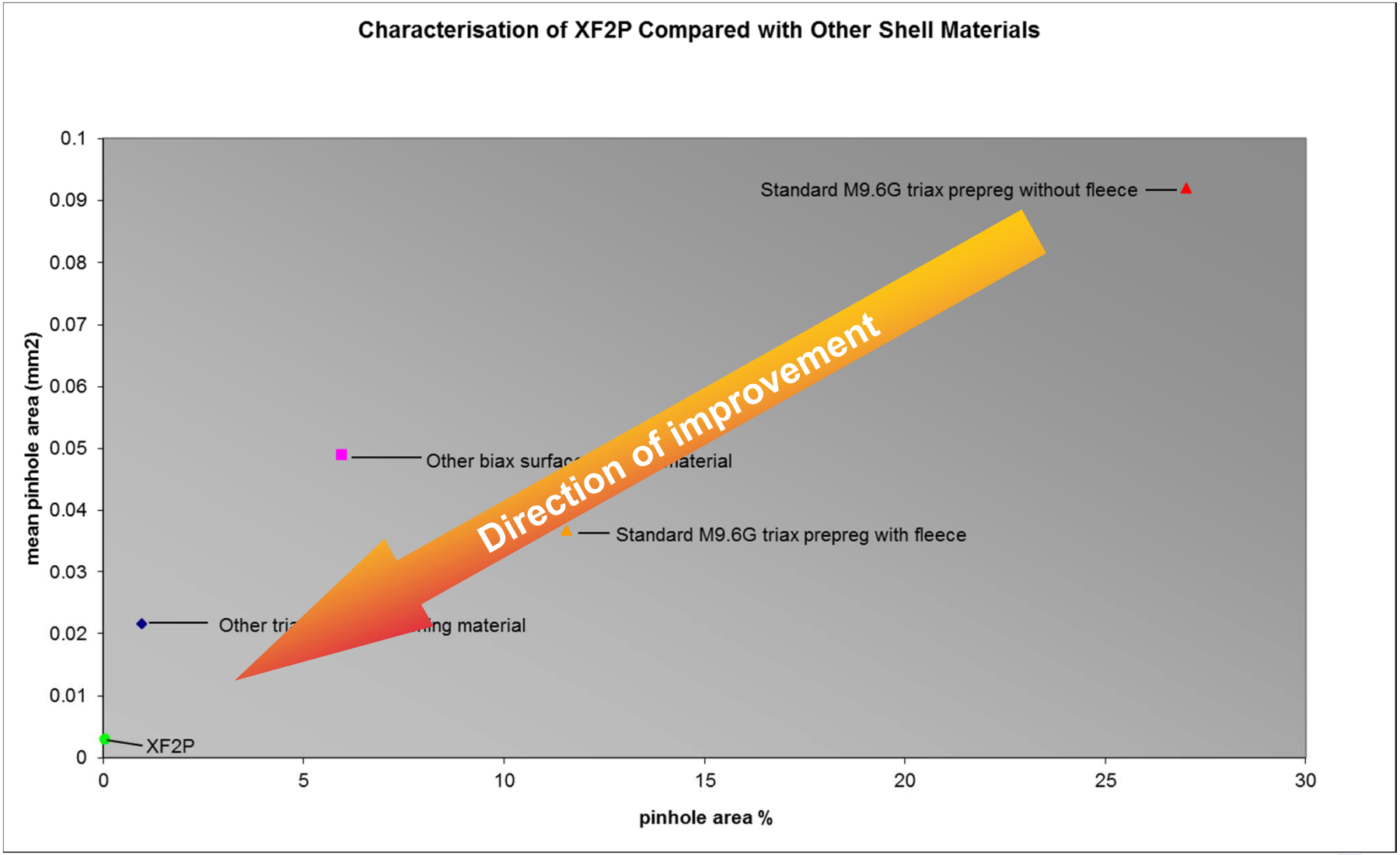
Surface Porosity from Shell Materials



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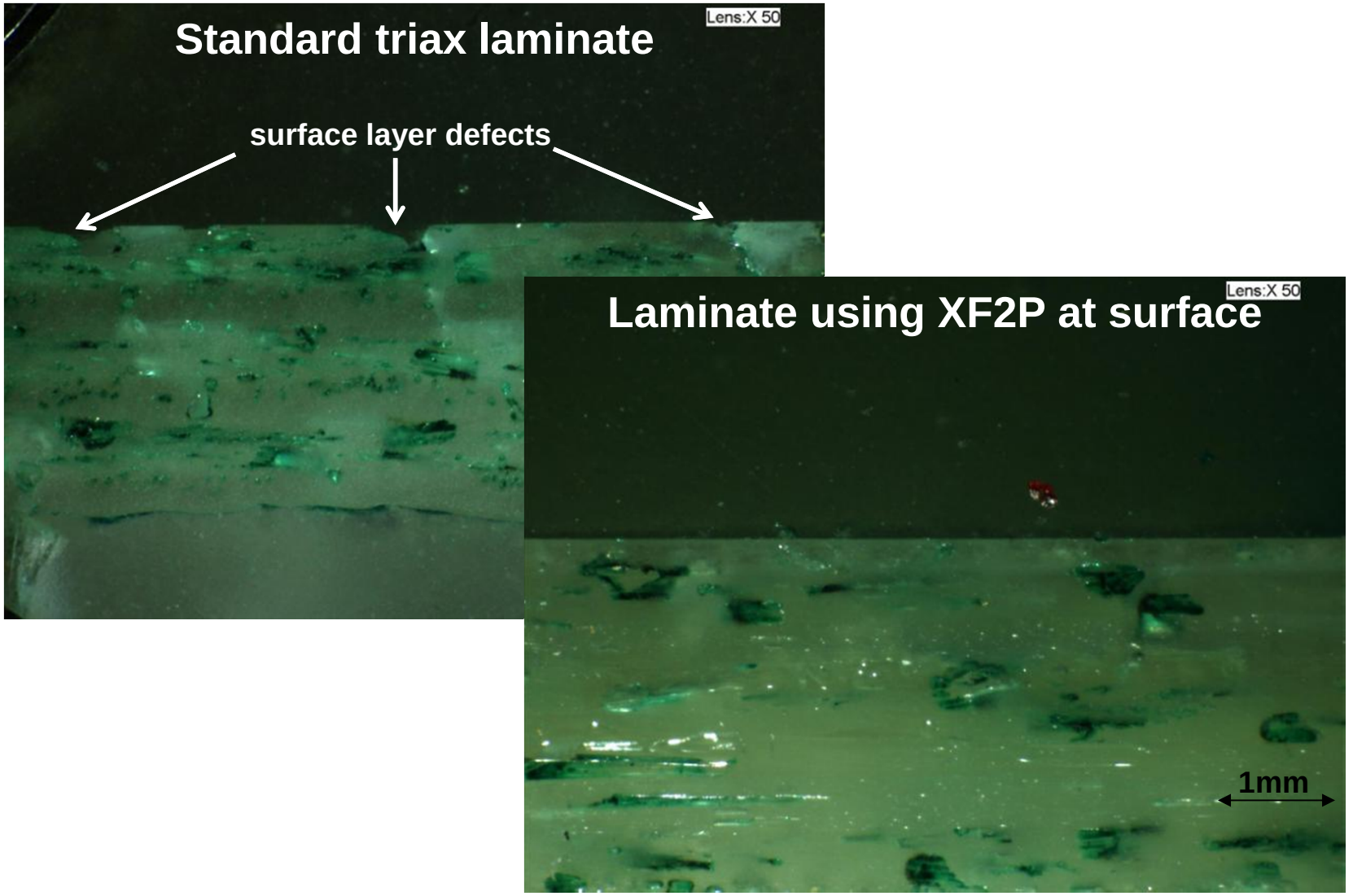
XF2P: Cross-sectional Analysis



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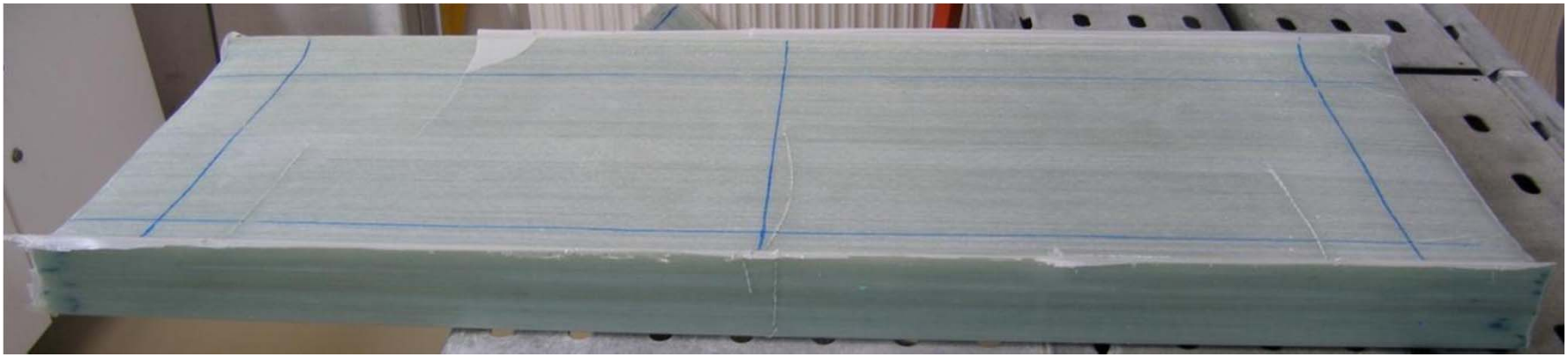
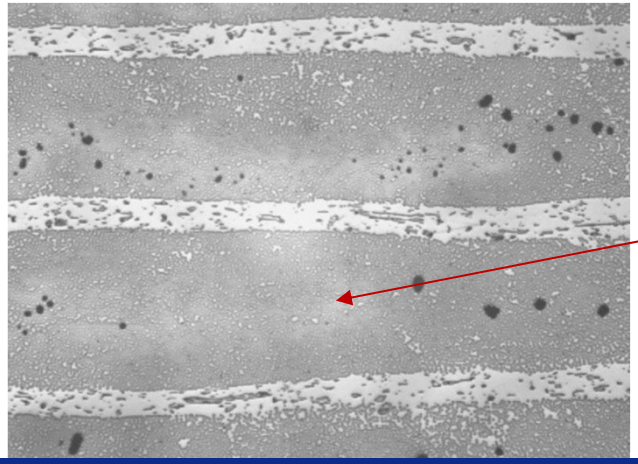
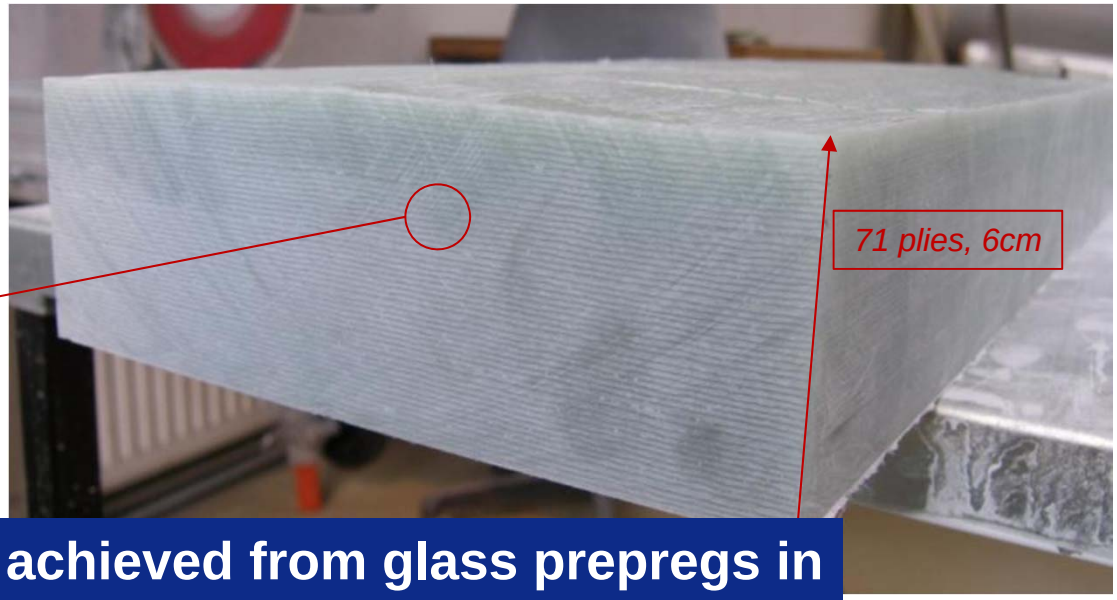
Prepregs for Thick Load-carrying Structures

Thick Glass Laminates using Prepregs







Very low porosities can be achieved from glass prepregs in thick laminates with optimised prepreg architecture

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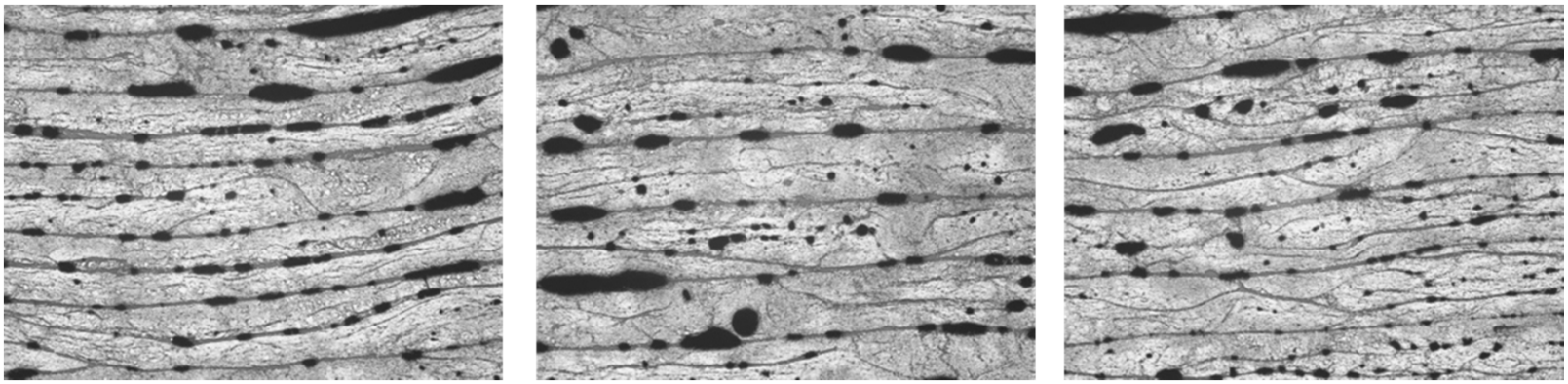
Thick Carbon Laminates – Conventional Technology



64 ply laminates using 600gsm carbon (HS) prepreg and conventional technology
Porosity ~7%

Conventional prepregs are not optimised for thick carbon laminates

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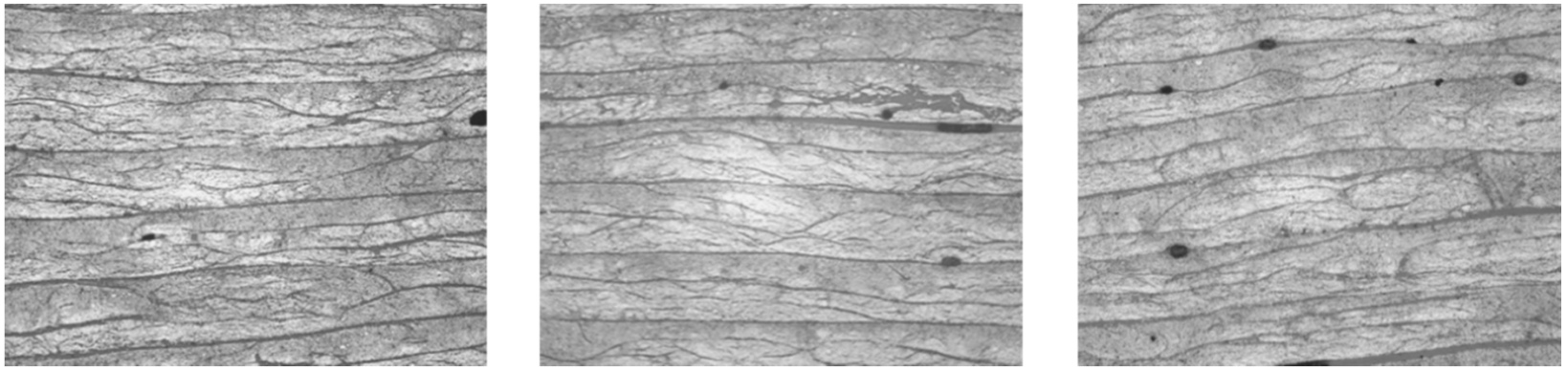
Thick Carbon Laminates – Optimised Architecture



Prepreg architecture designed for thick laminates
using Hexcel technology
Porosity <<1%

Optimised architecture in carbon UD prepregs consistently gives low porosity

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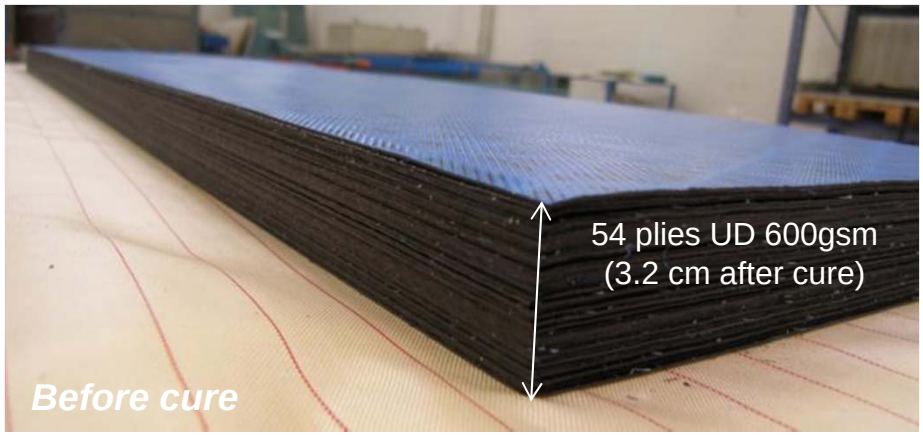
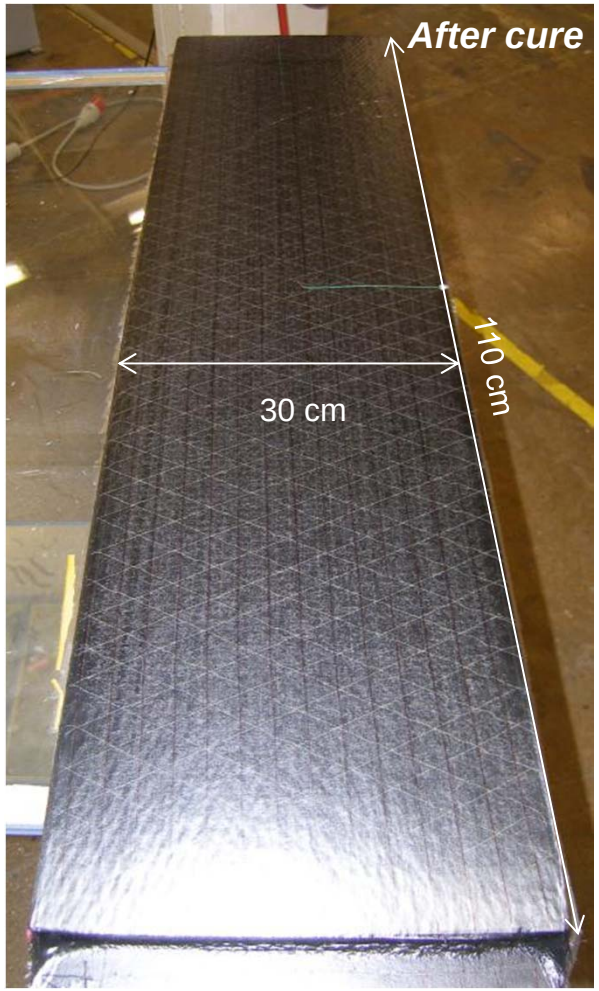
Thick Carbon Laminates – Optimised Architecture





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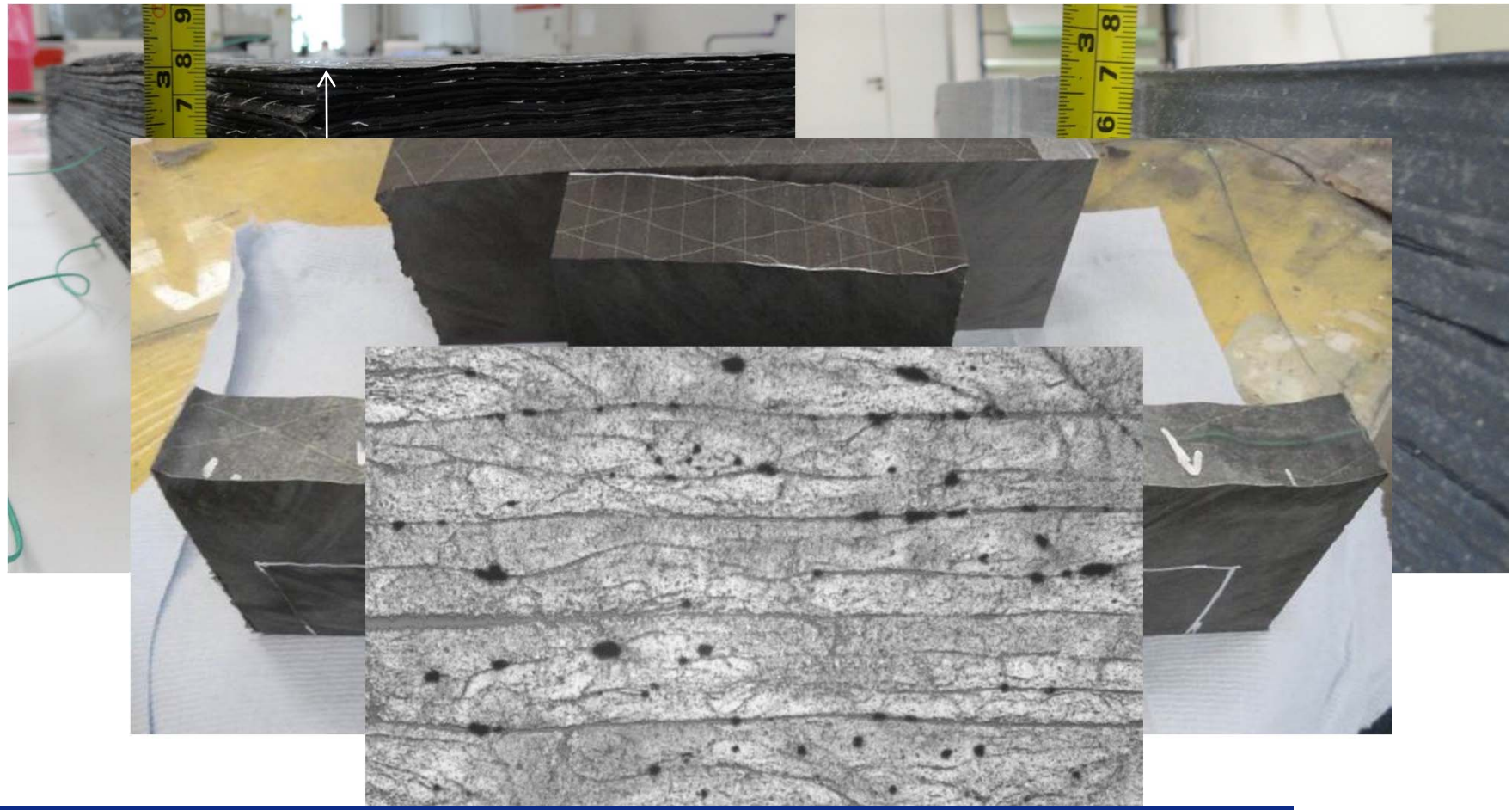
Thick Carbon Laminates – Optimised Architecture



Even in the thickest laminates, optimised architecture consistently gives low porosity

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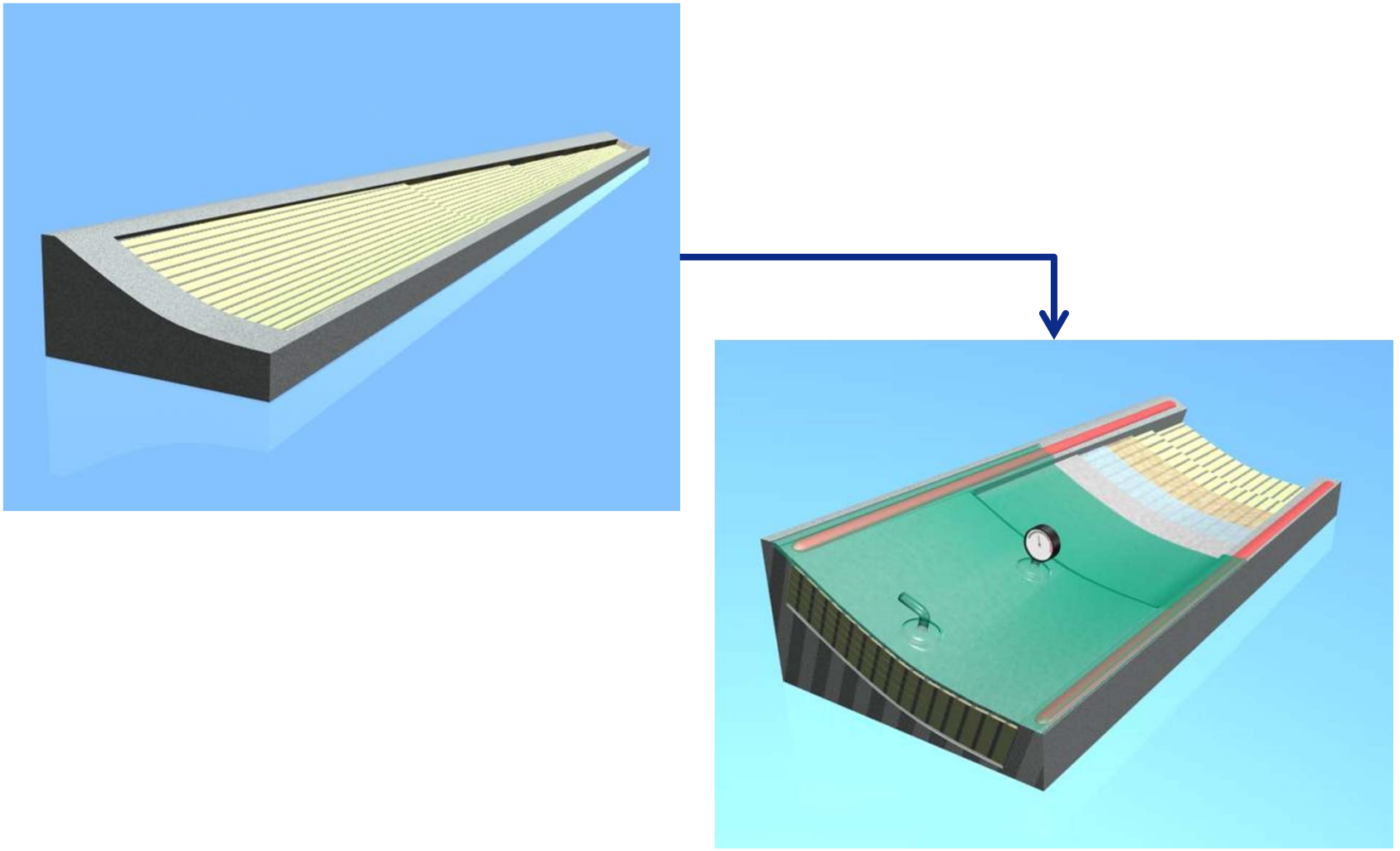
Use of Prepregs for the Construction of Spar Caps

Example 1

Pre-cured Spar Cap for Infusion and Final Cure

Spar Caps: Prepreg Layup and Cure



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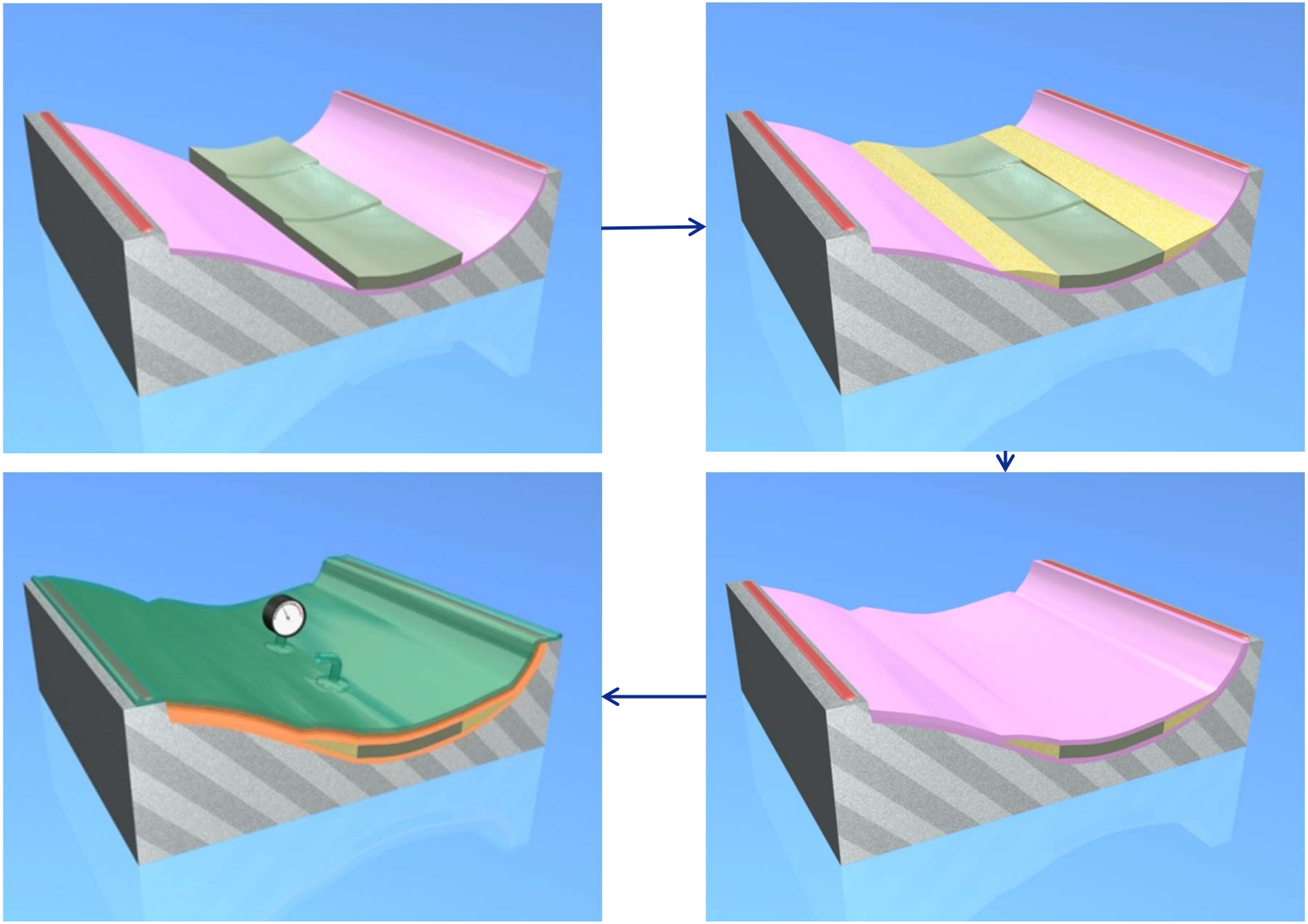
Spar Caps: Inclusion in an Infused Shell



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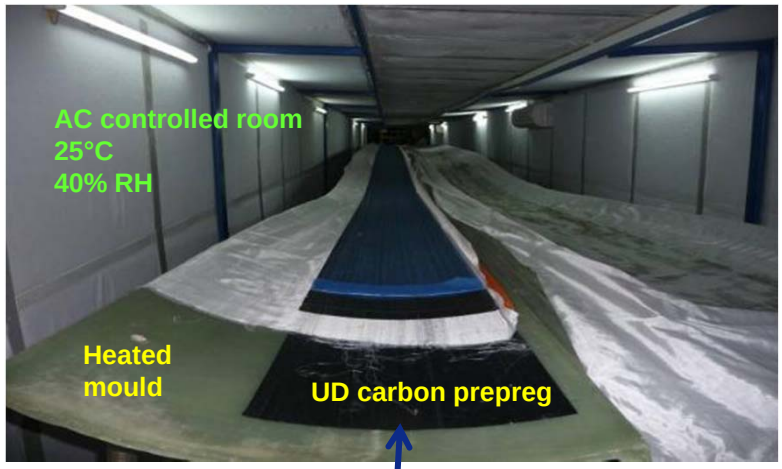
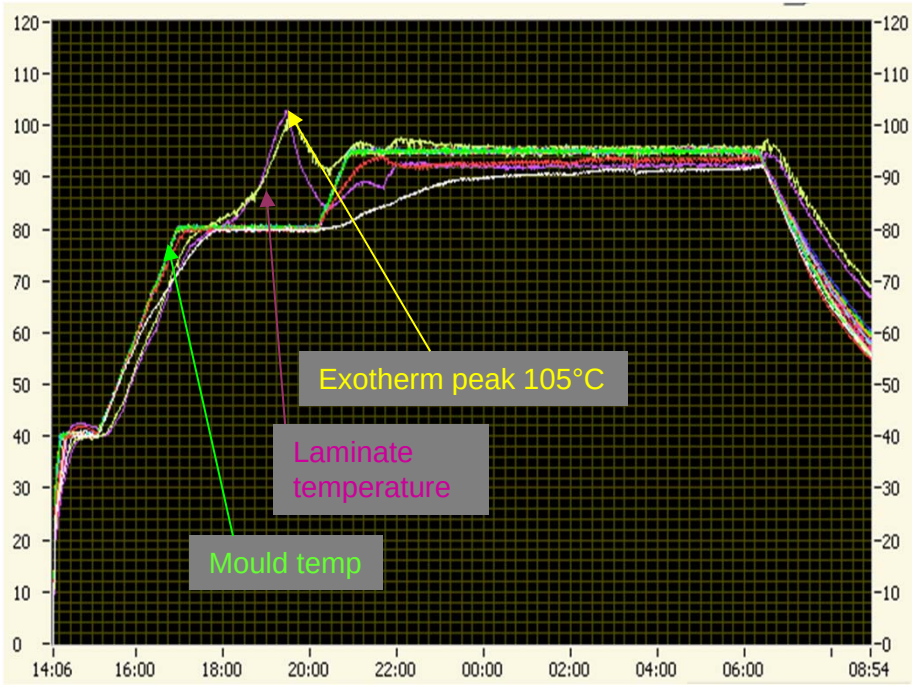
Case Study: Carbon Spar Cap at Half Scale

Carbon spar cap:	**length**	**25 m**
	width	**0,40 m**
	thickness	**22 mm**
Number of plies		**43**
Material		**M9.6/32%/500+8P/C**



UD prepregs are ideally suited to automated layup



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Use of Prepregs for the Construction of Spar Caps

Example 2

Prepreg Spar Cap Co-infused in the Shell with Final Co-cure

Co-infusion: an Introduction

Co-infusion

The use of prepreg and infusion technologies in the same laminate with co-cure

Typical configuration

UD prepreg for the heavy load-carrying structure
Infusion of dry reinforcement for the remainder of the structure
Cure of the whole assembly at the same time and temperature

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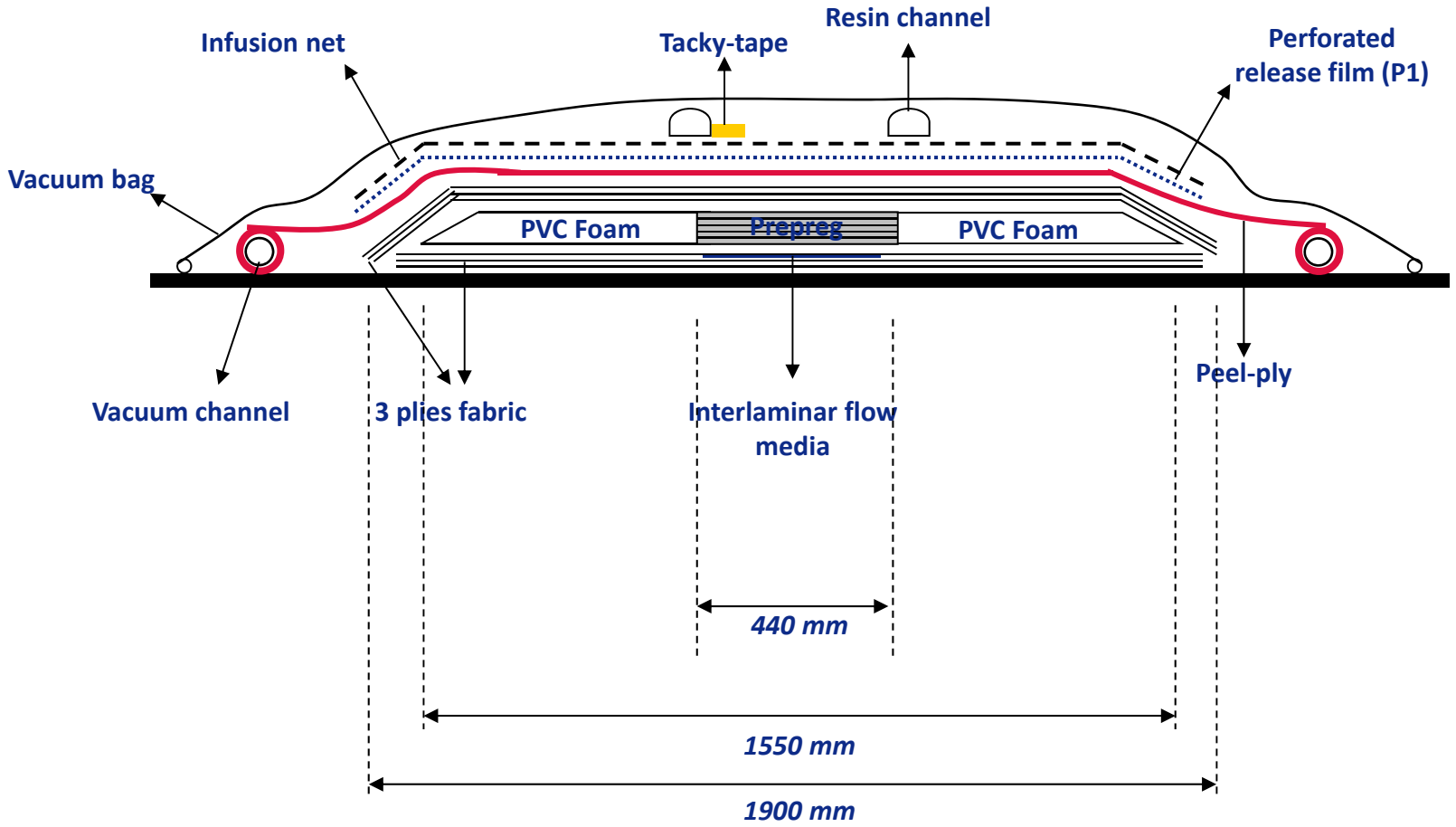
Co-infusion: Case Study, Construction

Demonstration on a 4 x 2m scale
UD prepreg with biax dry fabrics



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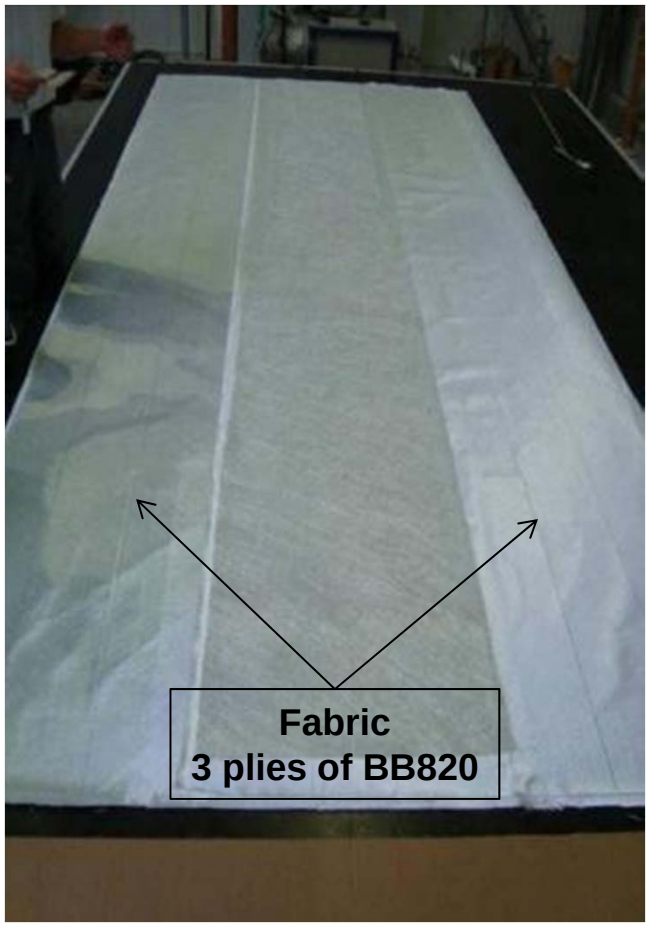
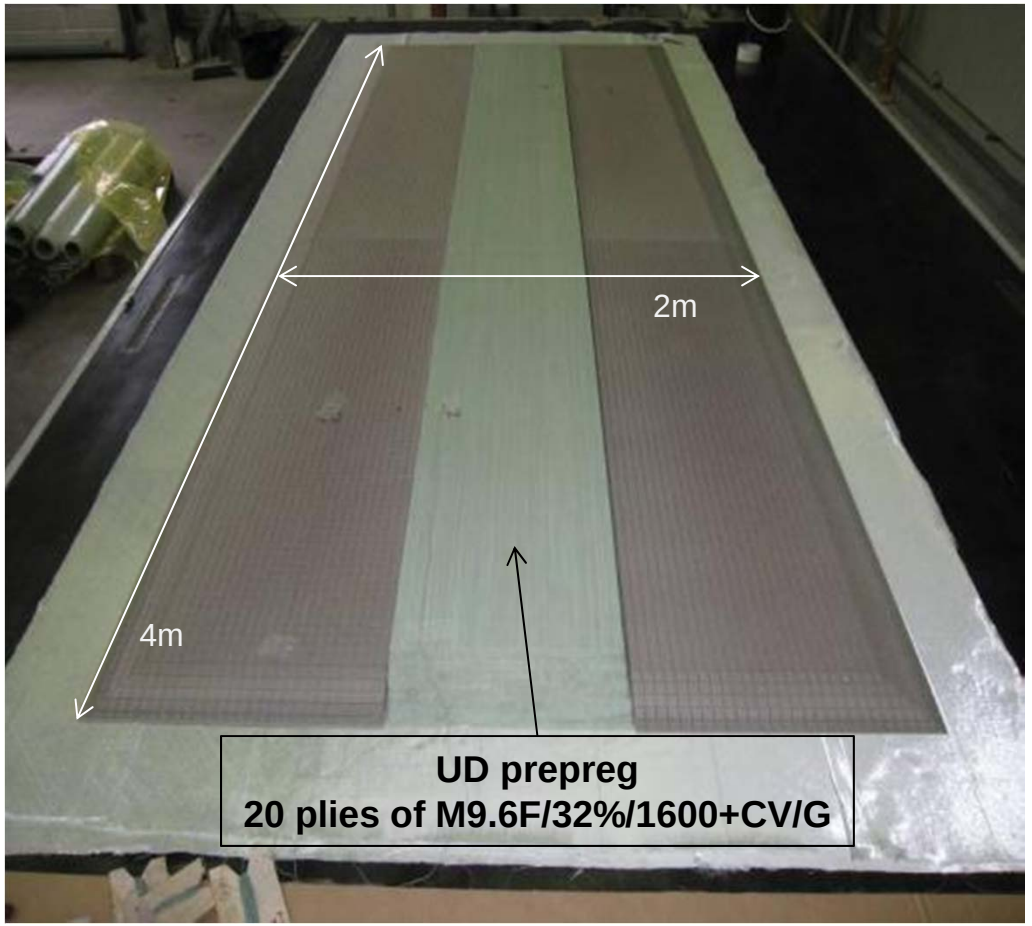
Co-infusion: Case Study, Layup



Dry reinforcements



Foam and UD prepreg layers

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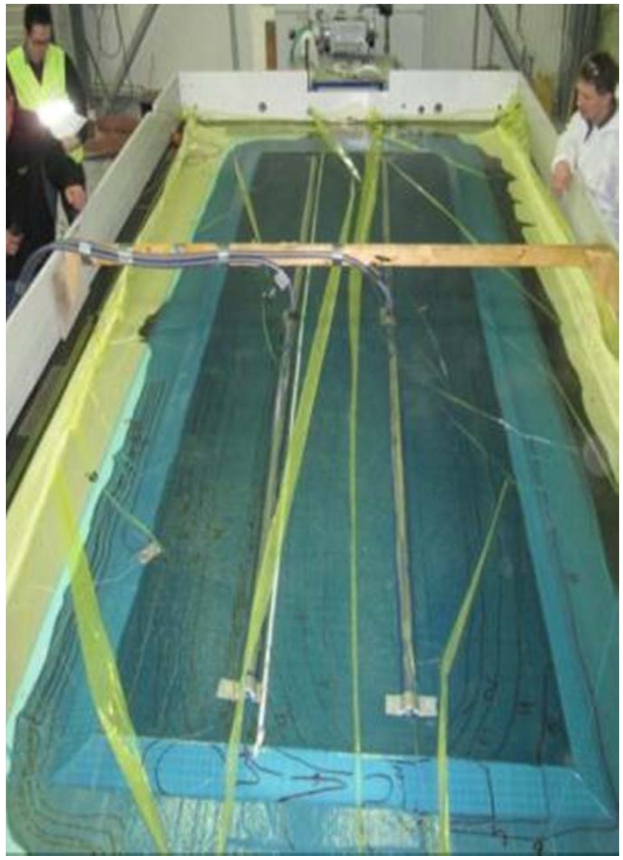
Co-infusion: Case Study, Infusion Process

1 min

12 min



22 min

Infusion time: ~25 min
Resin consumption: ~34 kg, Epikote RIM 135

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Co-infusion: Case Study, Demoulding

Full impregnation of the laminate

Low porosity, high Tg

FV (%)		50
Porosity (%)	Side	0,7
	Middle	1,5
Tg (°C)	Top	75
	Middle	120
	Bottom	75
Cure cycle		6hrs 90°C

Co-infusion simplifies the production process, combining the best features of prepreg and infusion materials

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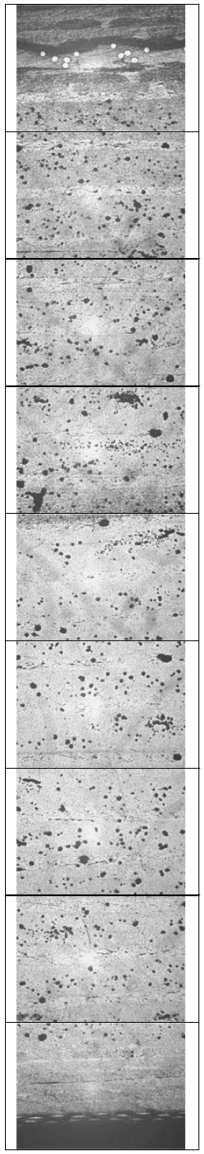
Co-infusion: Case Study, Porosity



3x Infusion fabrics

20x M9.6F/32%/1600+CV/G

3x Infusion fabrics

Porosity assessment	
Maximum void	<0.85 mm^2
Porosity	0.7-1.5%

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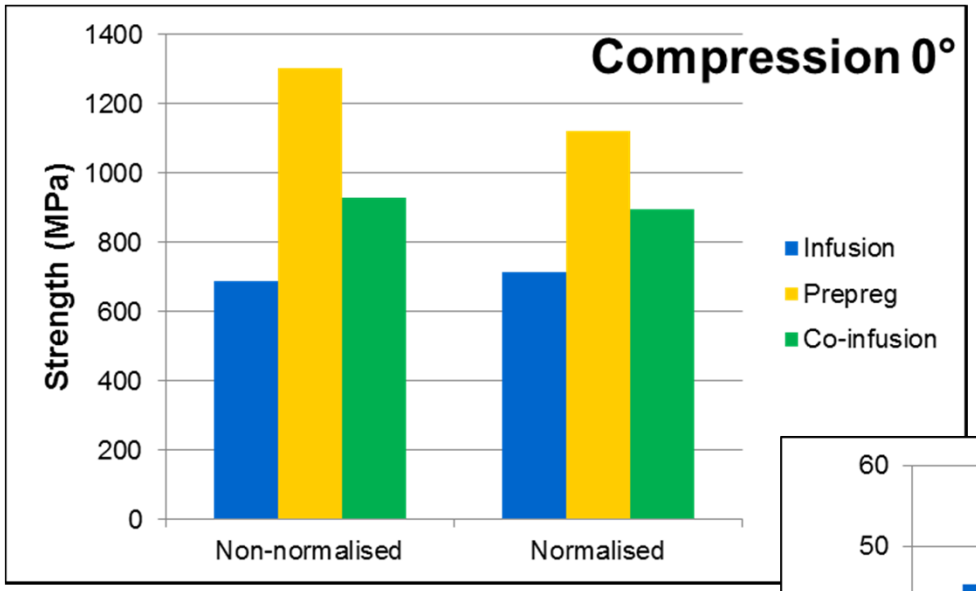
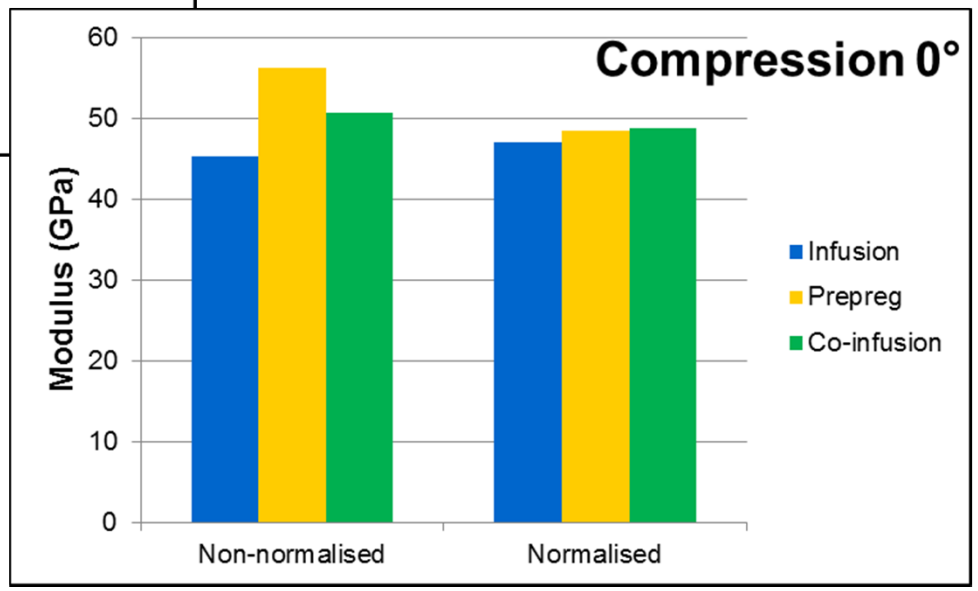
Co-infusion: Case Study, Compression



* ISO 14126



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Conclusions

Prepregs can be tailored for optimal wind blade manufacture

- **Reaction exotherms can reduce to <100 j/g**
- **Cure temperatures can reduce to 70-80°C**
- **Minimal porosity from well-designed architecture**
  - Both within the laminate and on the surface
- **Reliable and full impregnation, even of carbon**

Prepregs are ideally suited for thick structural sections

Co-infusion simplifies the manufacturing process

- **It eliminates the separate steps for spar cap production**

Carbon and glass prepregs are ideally suited to heavy load-critical structures in wind blades

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