Recent Developments in Materials and Processes for Blades at Hexcel

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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**

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**






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)

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

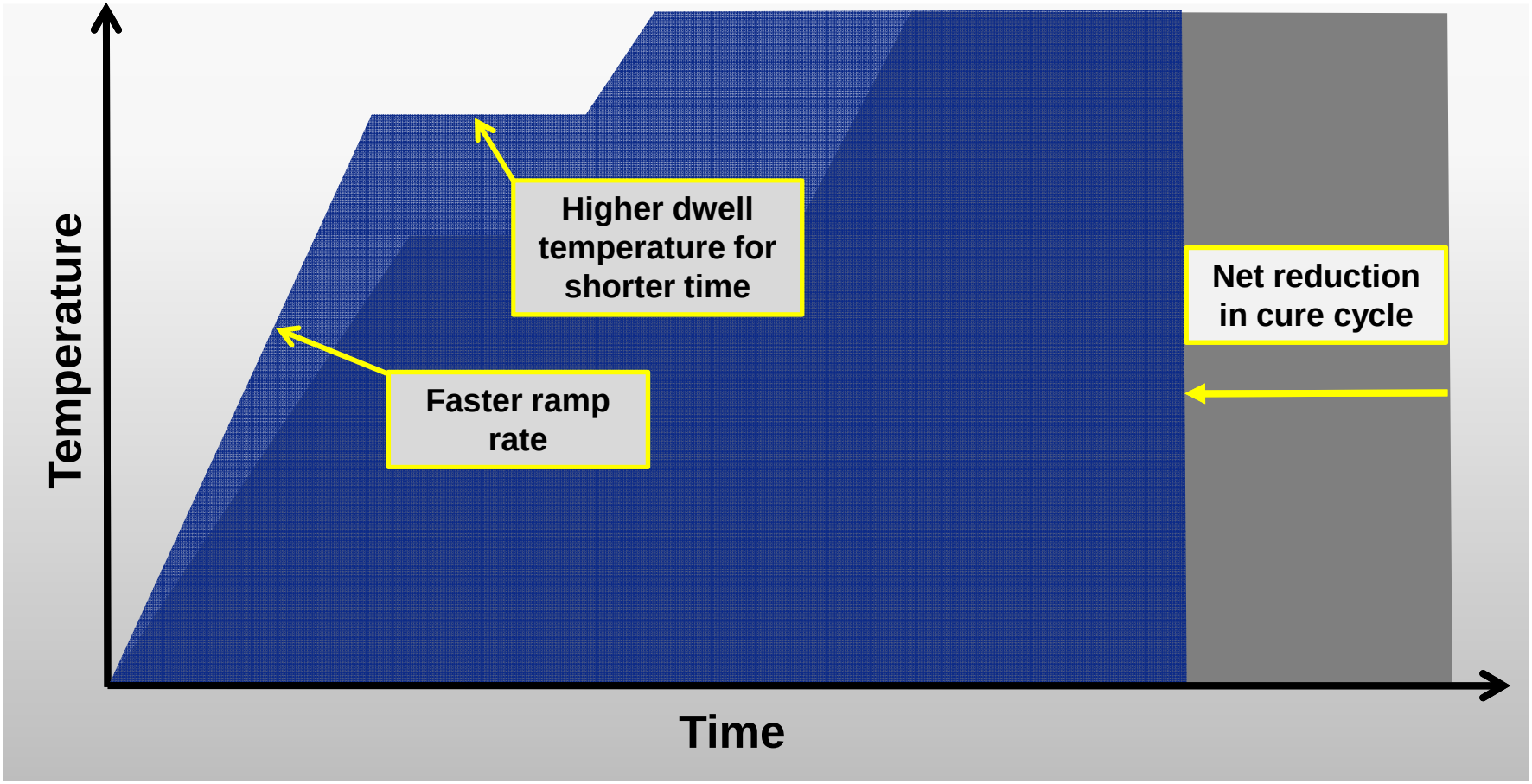
Storage	
Temperature	Shelf life
+23°C	6 weeks
+5°C	6 months
-18°C	18 months

Overall cure cycles

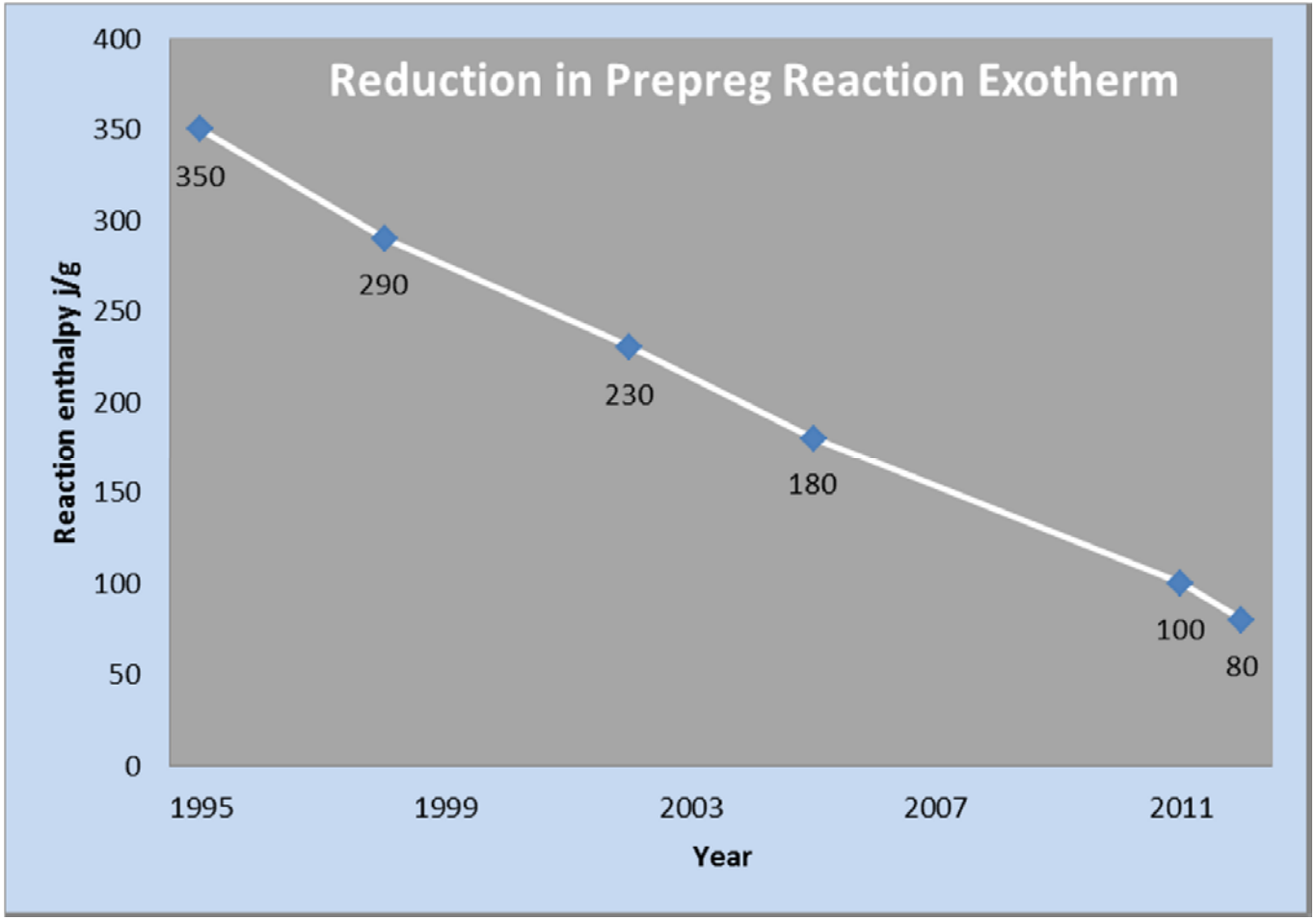
~4 to ~8 hours (optimisation is key)

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

The Value of Low Exotherm in Thick Laminates



The Trend to Lower Exotherm, 1995-2012



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

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

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

Prepregs for the Surface

Prepregs for the Shell Surface

Shell prepregs are used for the aerodynamic shell

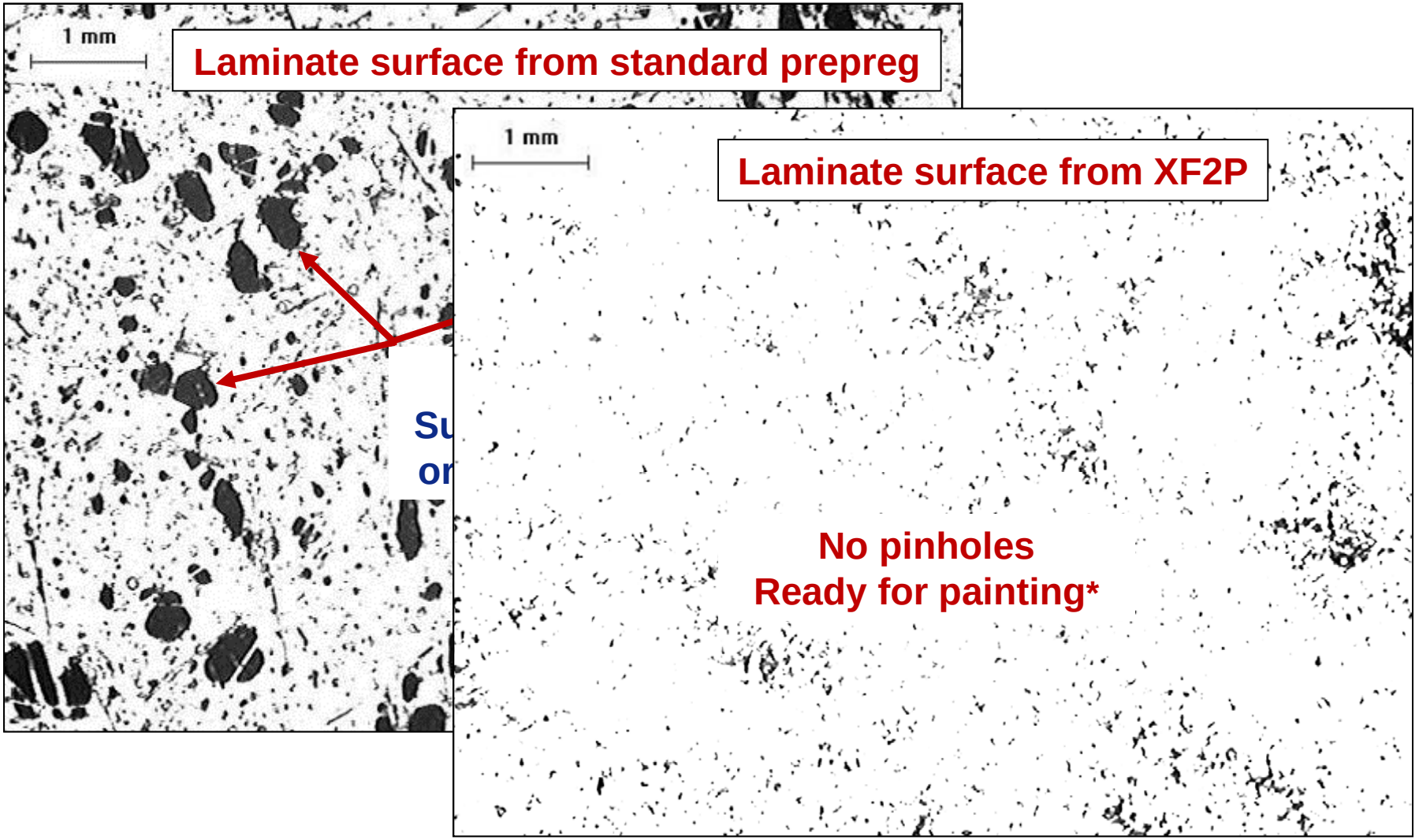
- Gel coats may be used to provide a good paint-ready surface
- Polyurethane paints may be used for the final surface

This process can be simplified by using specific shell prepregs

e.g. Products such as XF2P

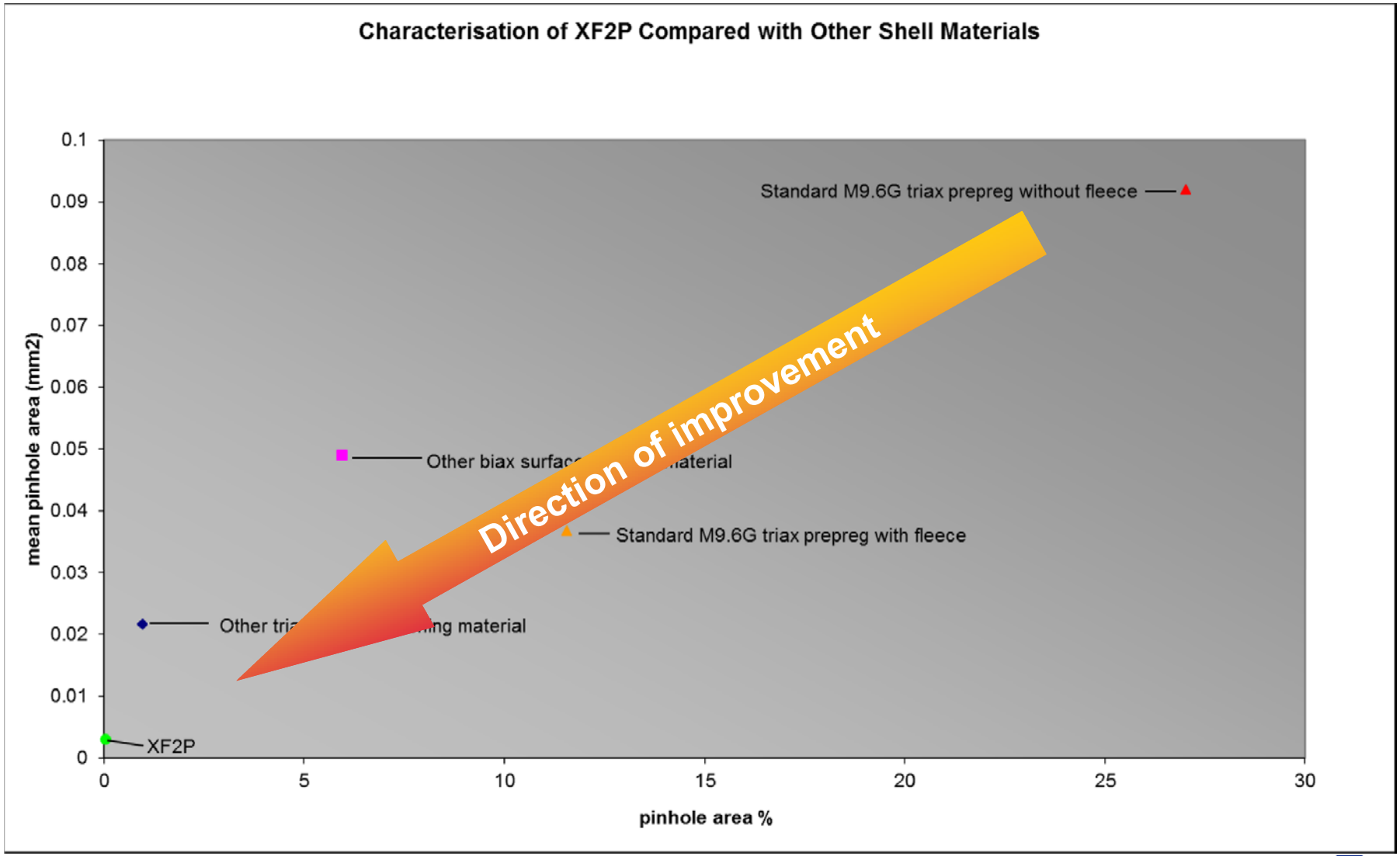
- Build the aerodynamic shell surface
- Eliminate the gel coat

XF2P: Surface Characterisation

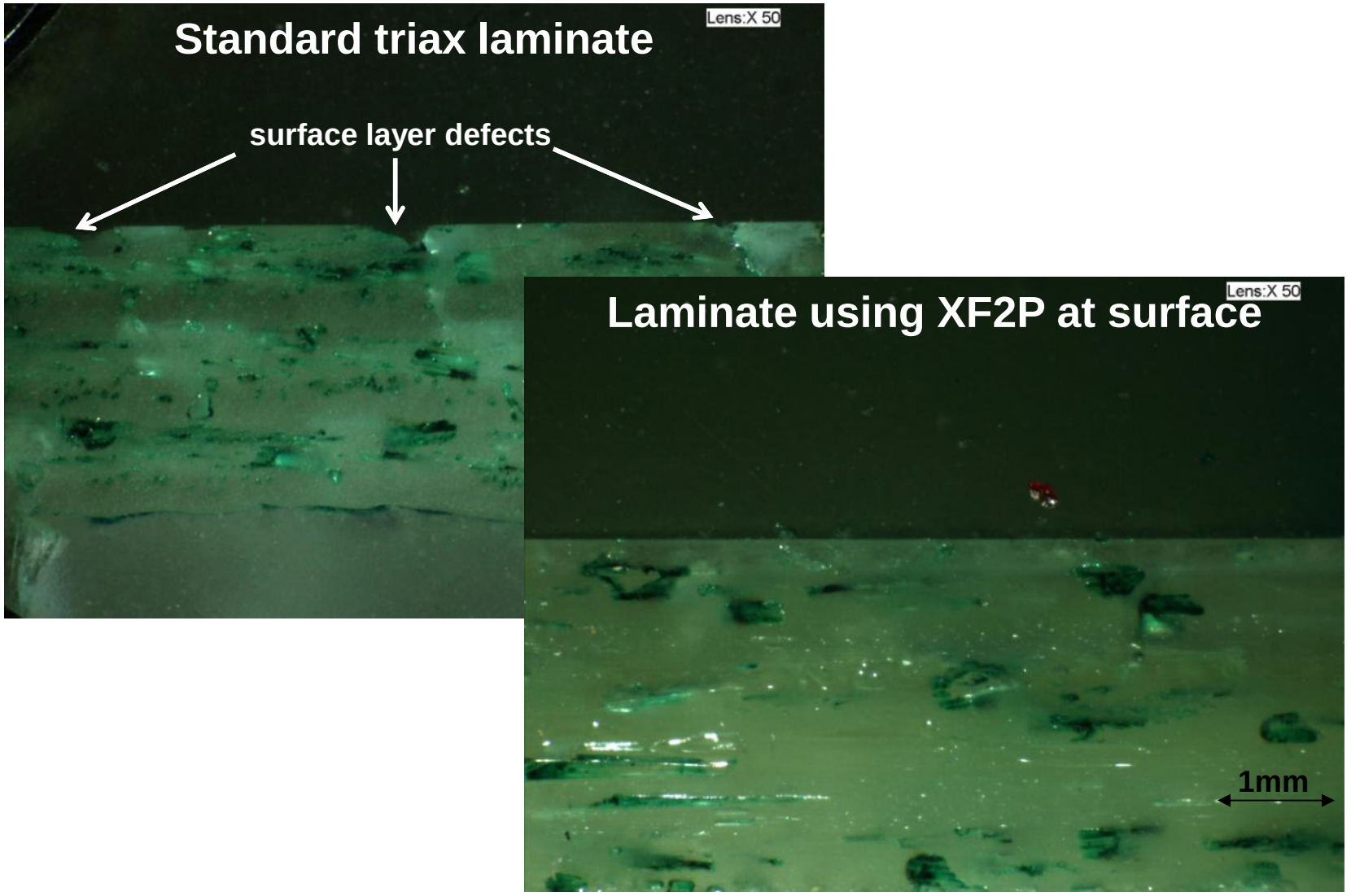


* After removal of release agent

Surface Porosity from Shell Materials

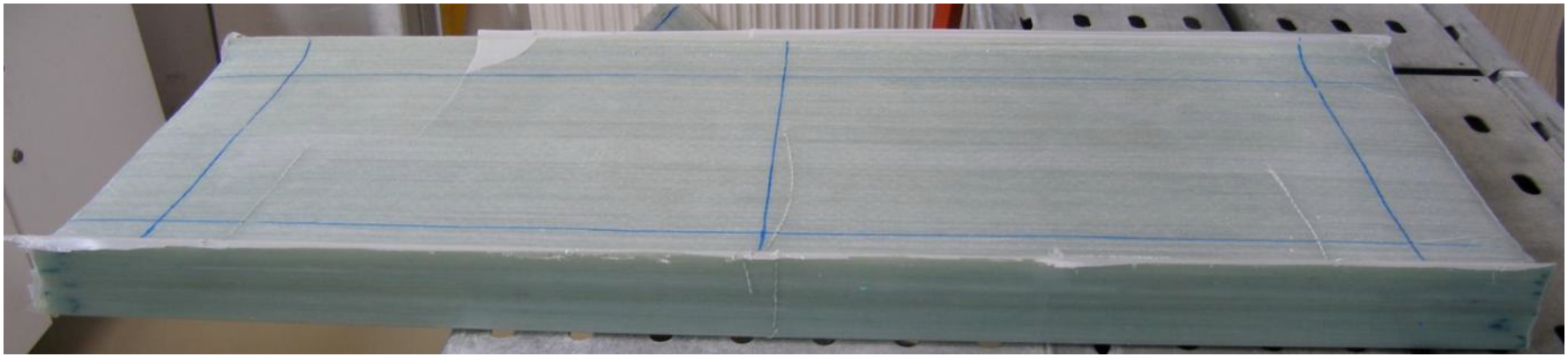


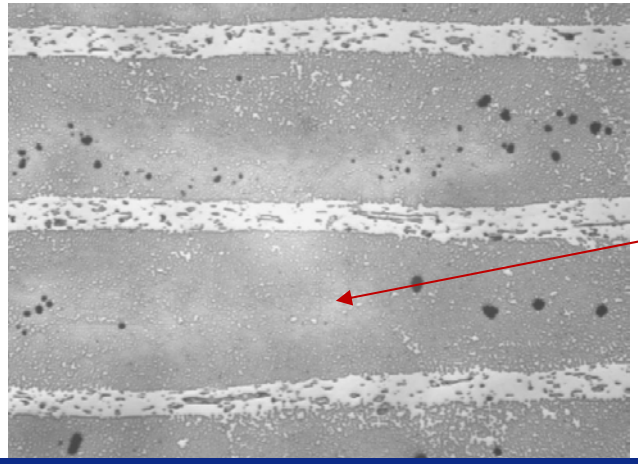
XF2P: Cross-sectional Analysis

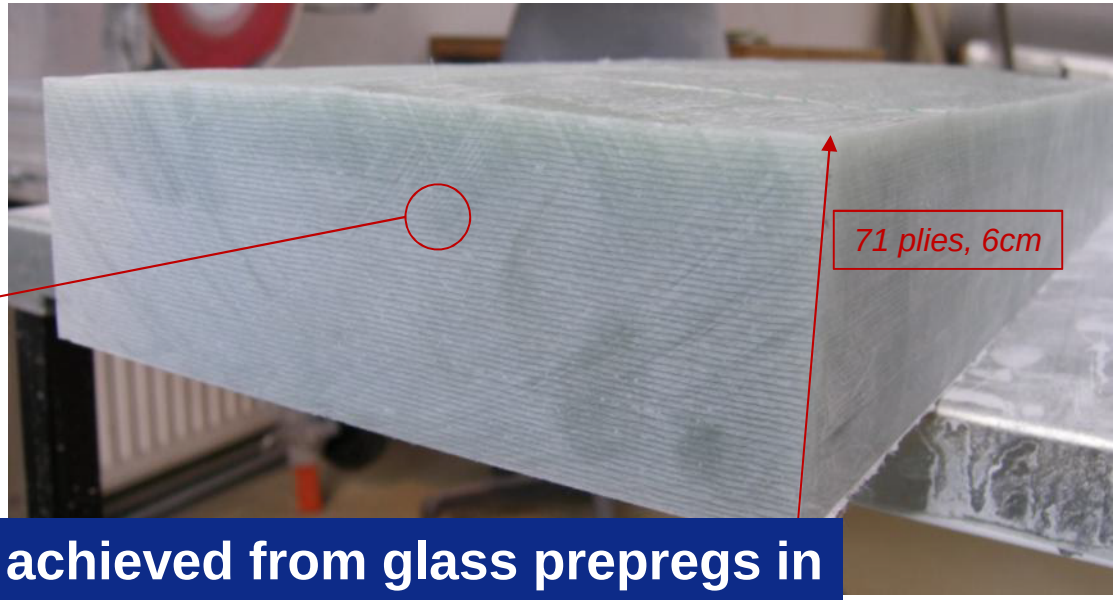


Prepregs for Thick Load-carrying Structures

Thick Glass Laminates using Prepregs

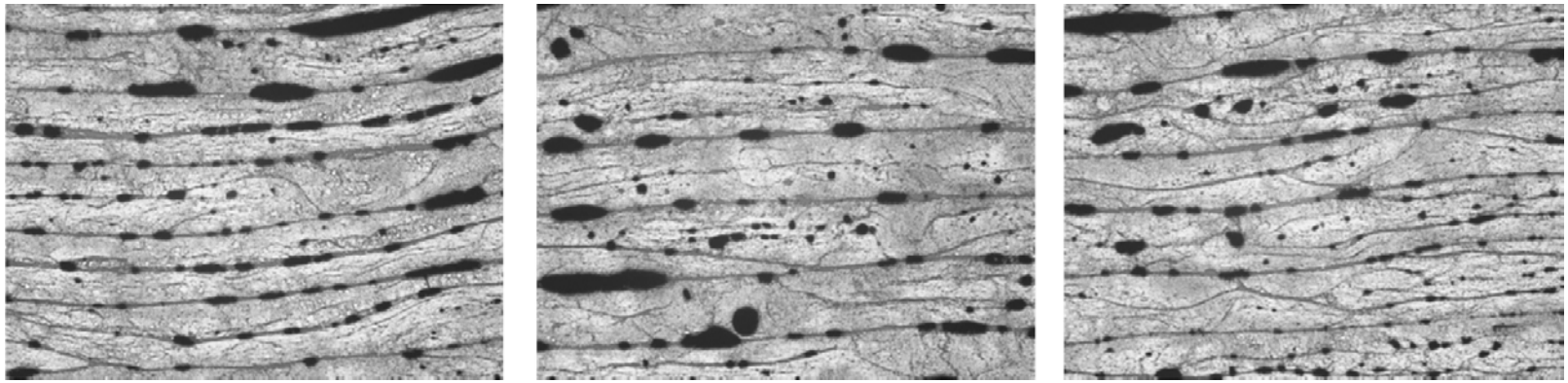






Very low porosities can be achieved from glass prepregs in thick laminates with optimised prepreg architecture

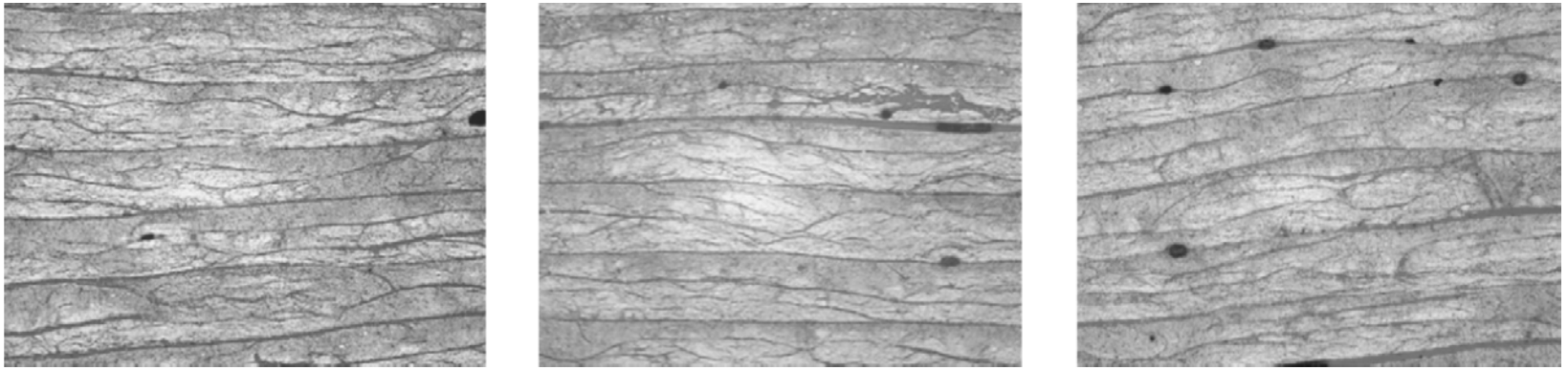
Thick Carbon Laminates – Conventional Technology



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

Conventional prepregs are not optimised for thick carbon laminates

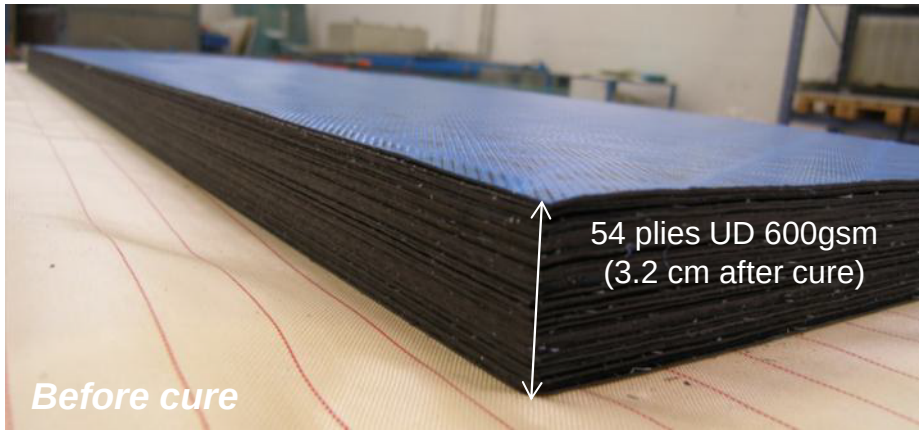
Thick Carbon Laminates – Optimised Architecture

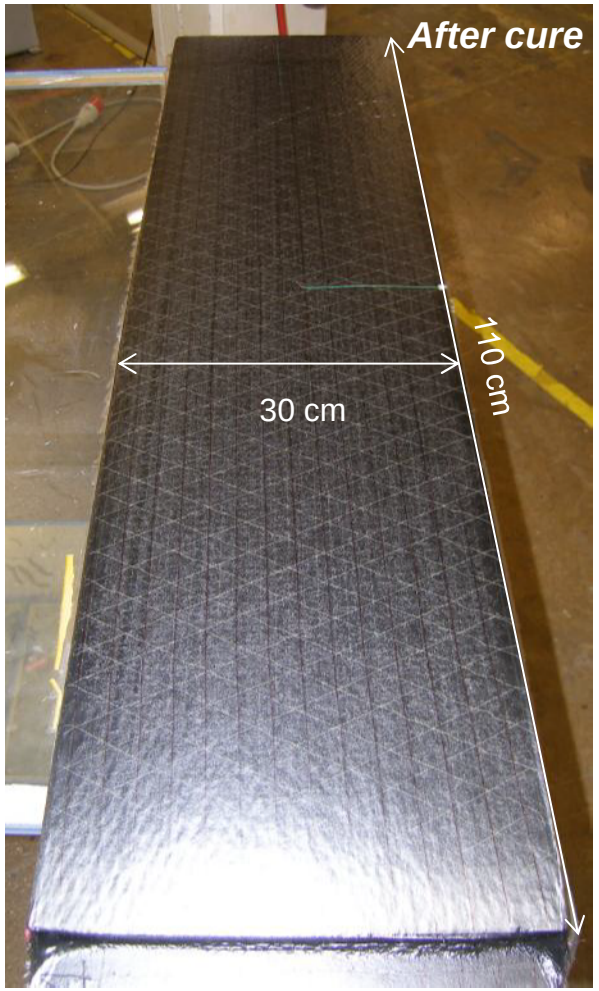


Prepreg architecture designed for thick laminates
using Hexcel technology
Porosity <<1%

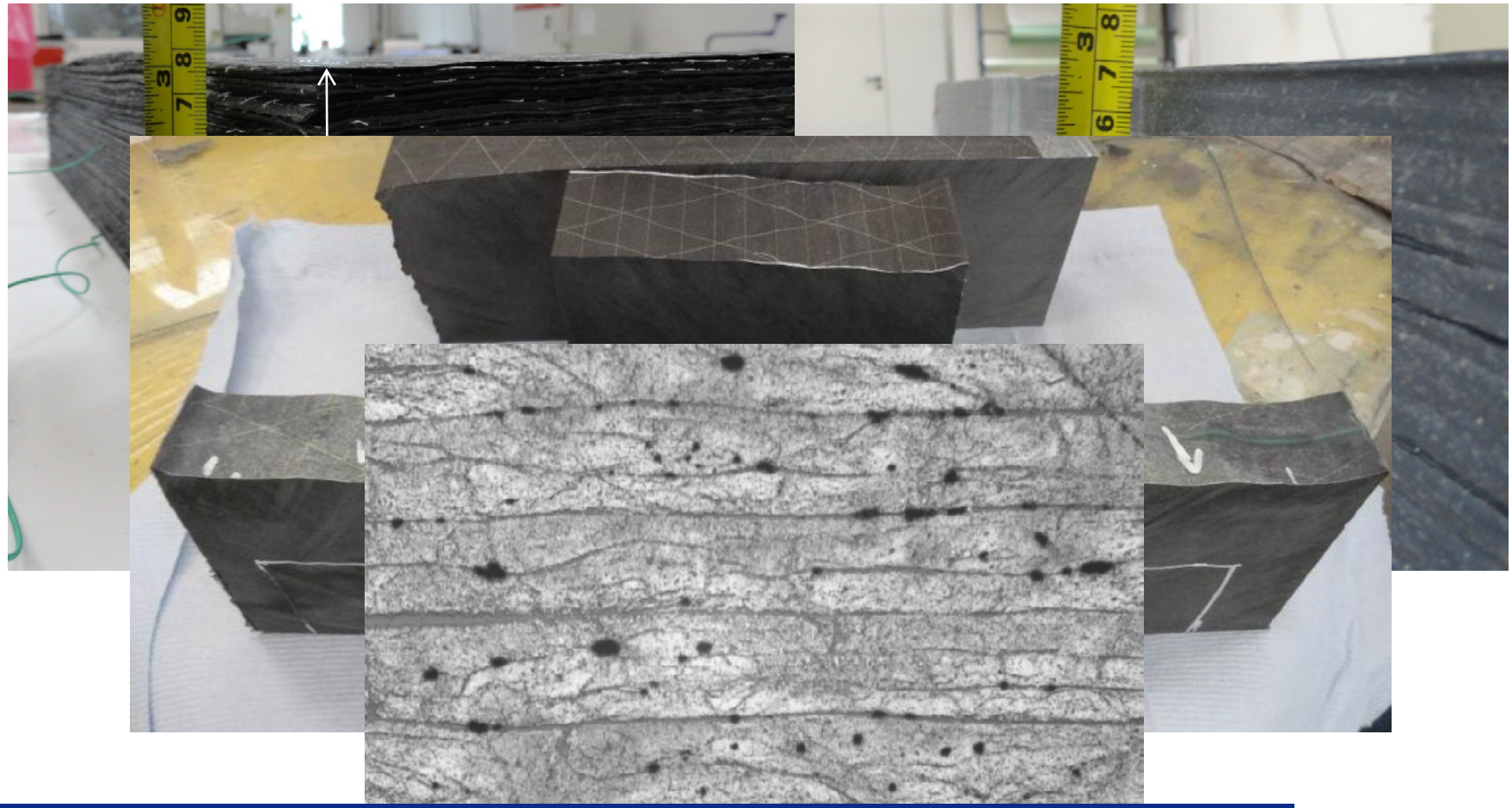
Optimised architecture in carbon UD prepregs consistently gives low porosity

Thick Carbon Laminates – Optimised Architecture





Thick Carbon Laminates – Optimised Architecture



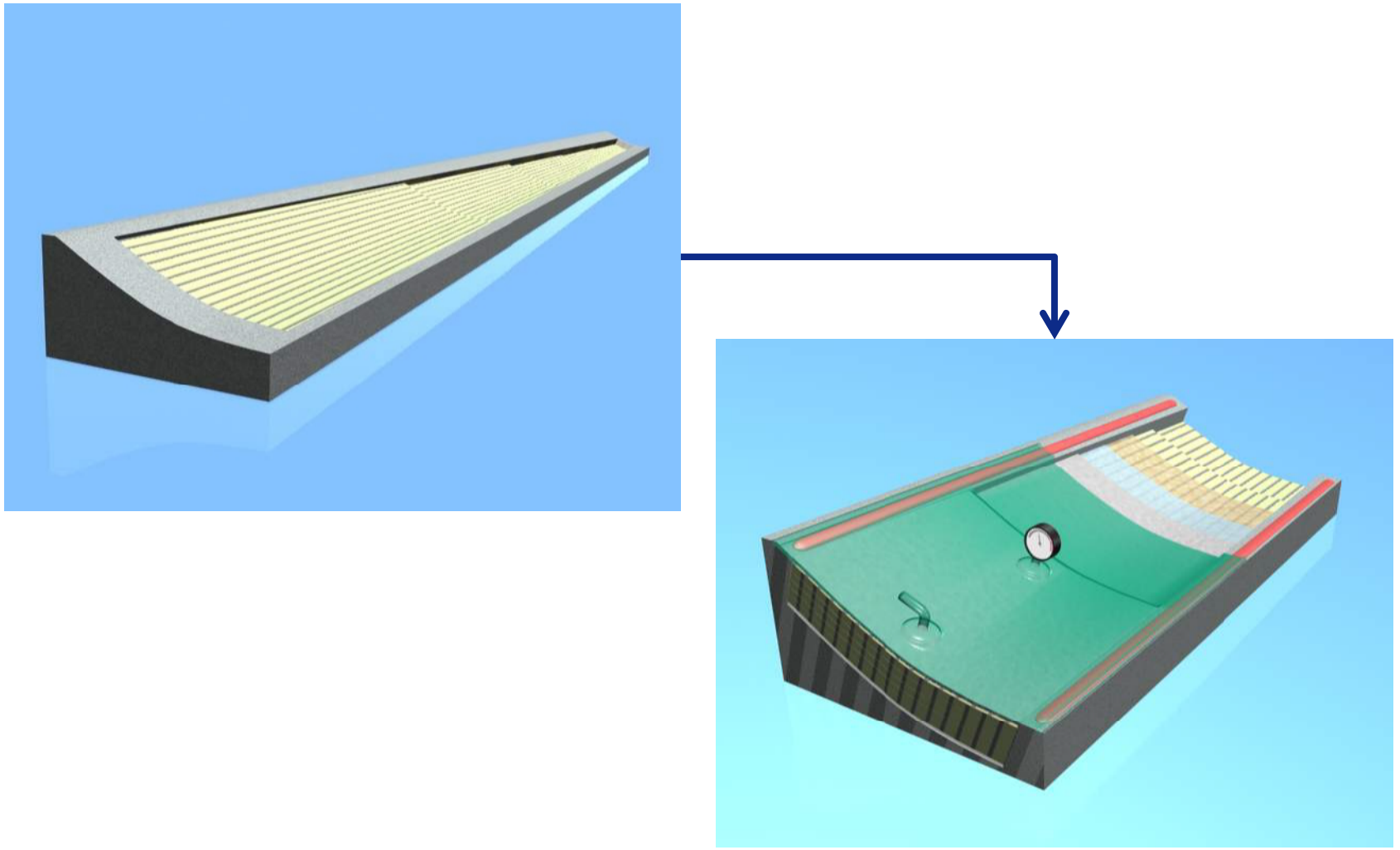
Even in the thickest laminates, optimised architecture consistently gives low porosity

Use of Prepregs for the Construction of Spar Caps

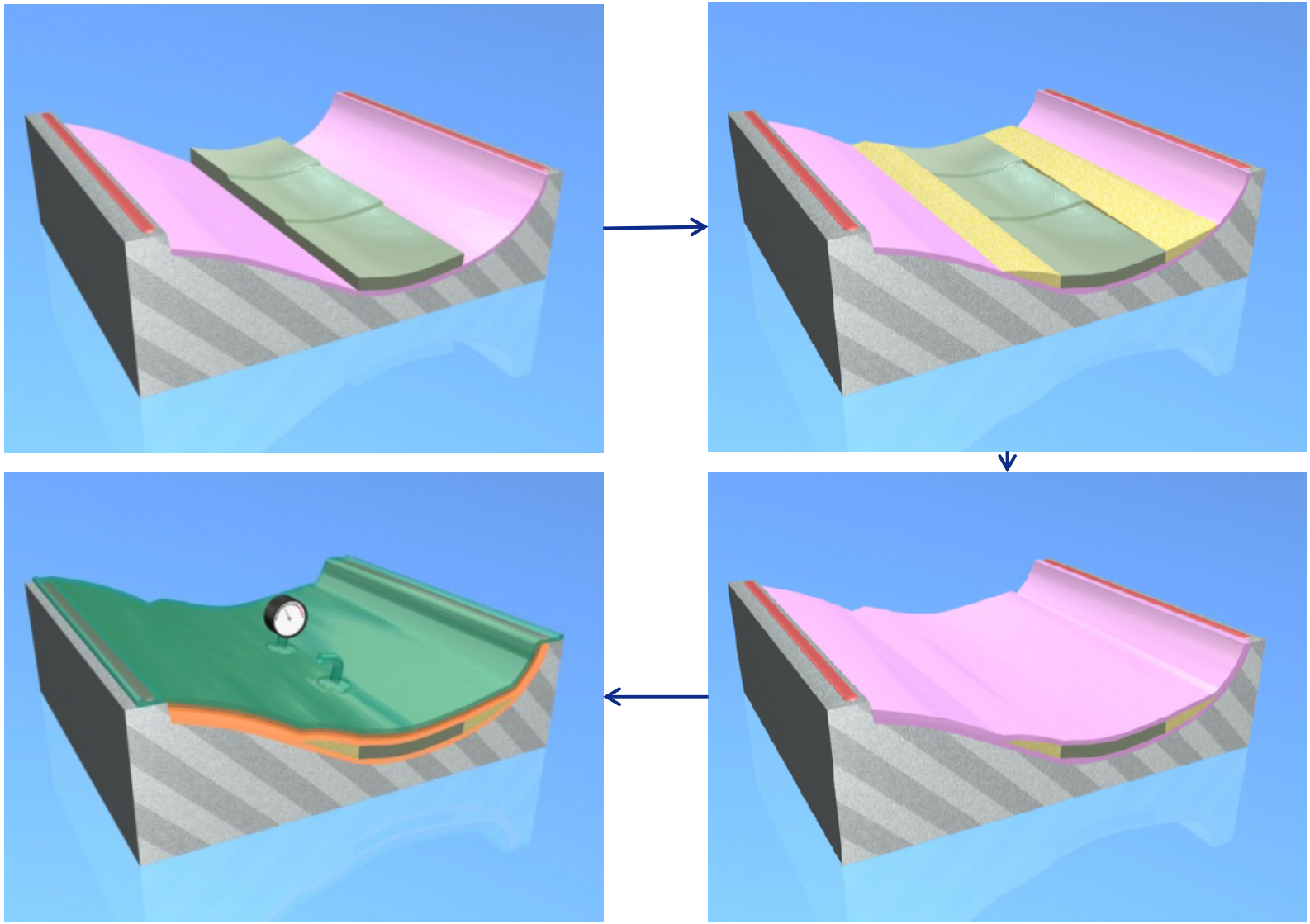
Example 1

Pre-cured Spar Cap for Infusion and Final Cure

Spar Caps: Prepreg Layup and Cure

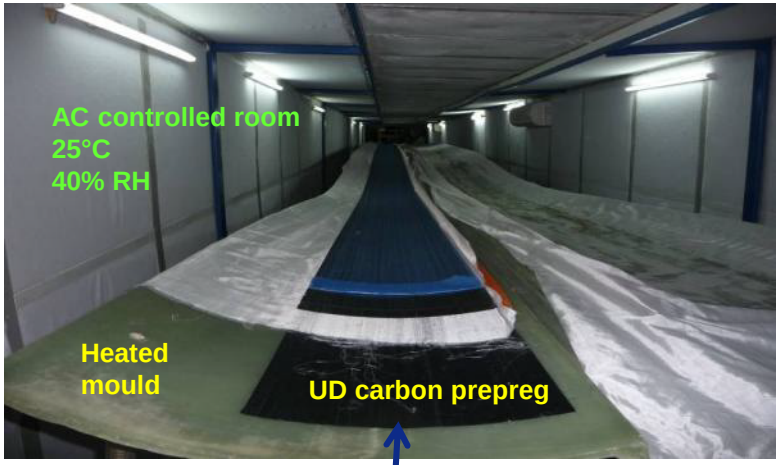


Spar Caps: Inclusion in an Infused Shell

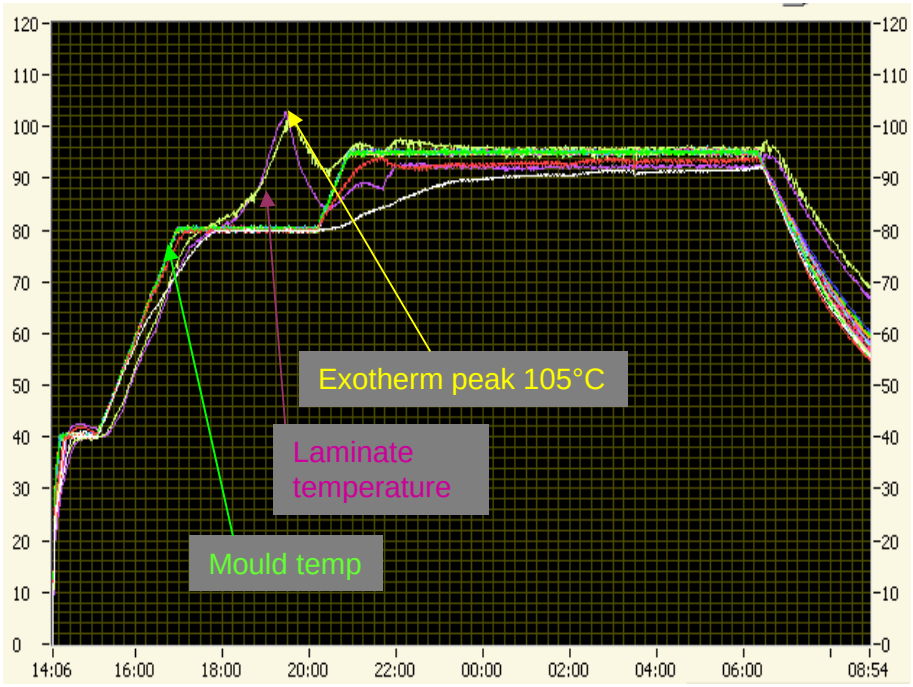


Case Study: Carbon Spar Cap at Half Scale

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



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

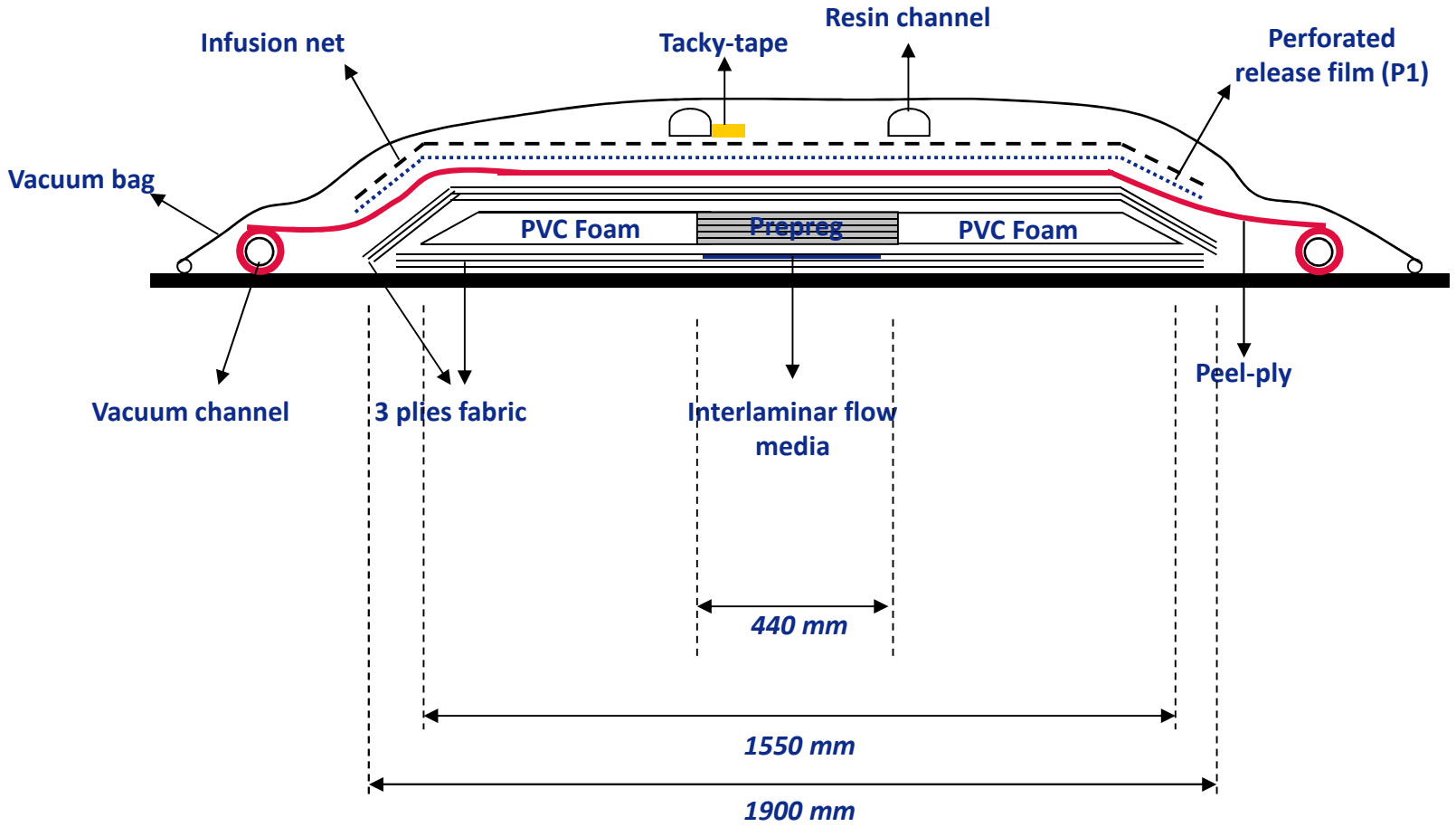
The use of prepreg and infusion technologies in the same laminate with co-cure

Typical configuration

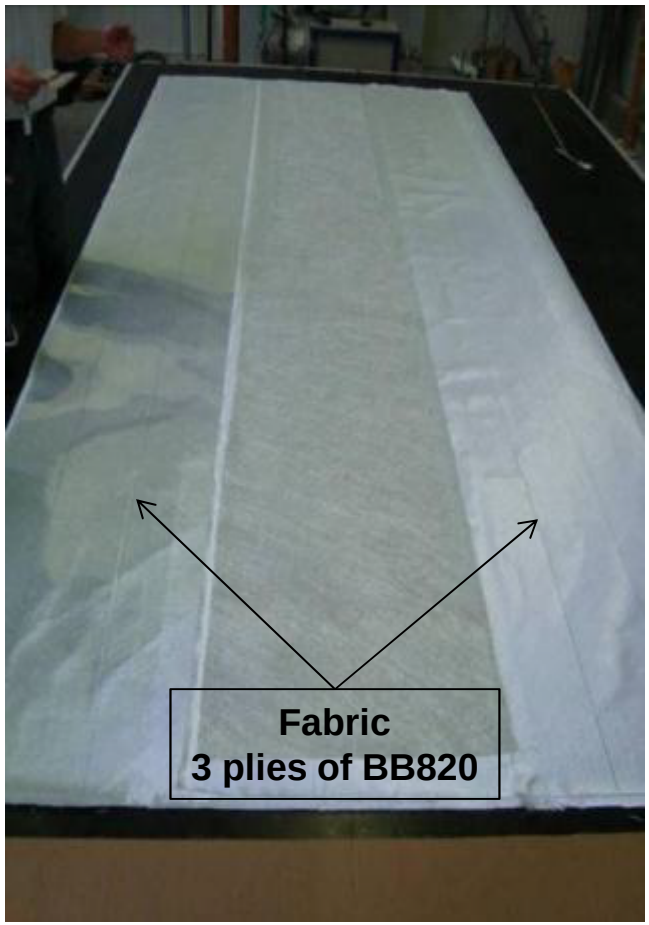
UD prepreg for the heavy load-carrying structure
Infusion of dry reinforcement for the remainder of the structure
Cure of the whole assembly at the same time and temperature

Co-infusion: Case Study, Construction

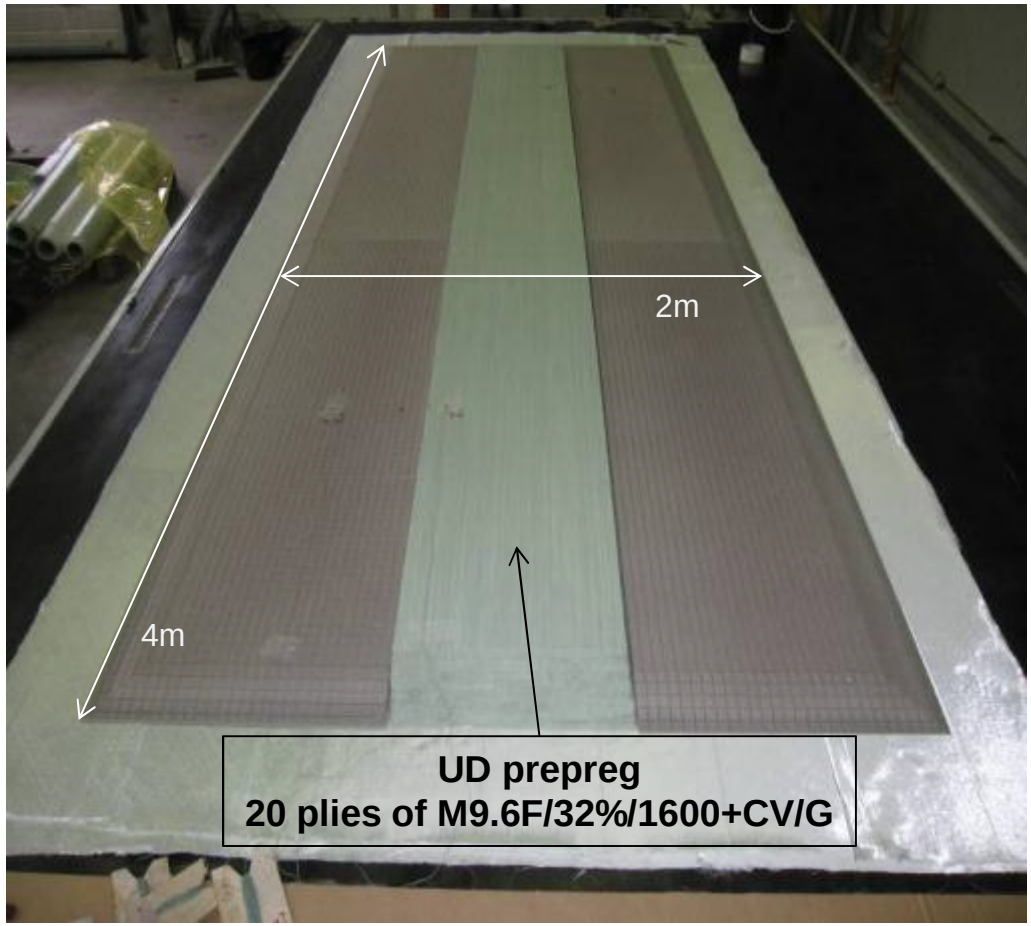
Demonstration on a 4 x 2m scale
UD prepreg with biax dry fabrics



Co-infusion: Case Study, Layup



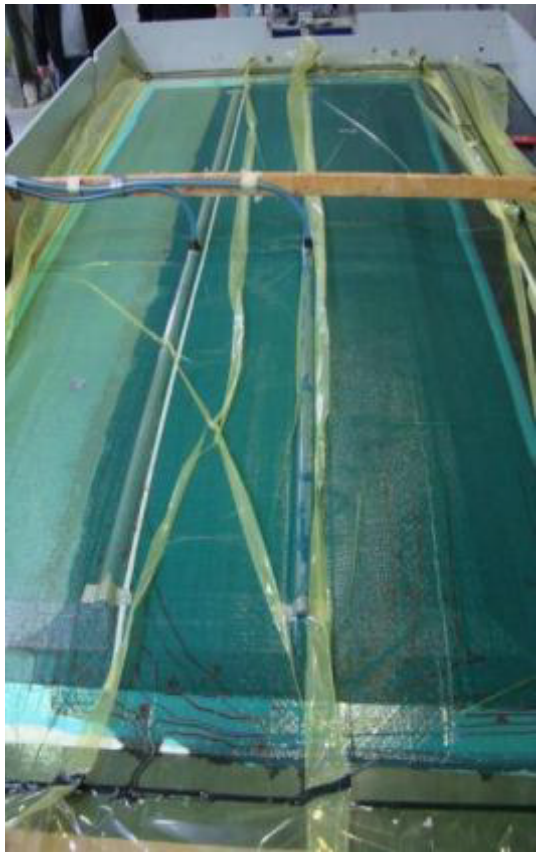
Dry reinforcements



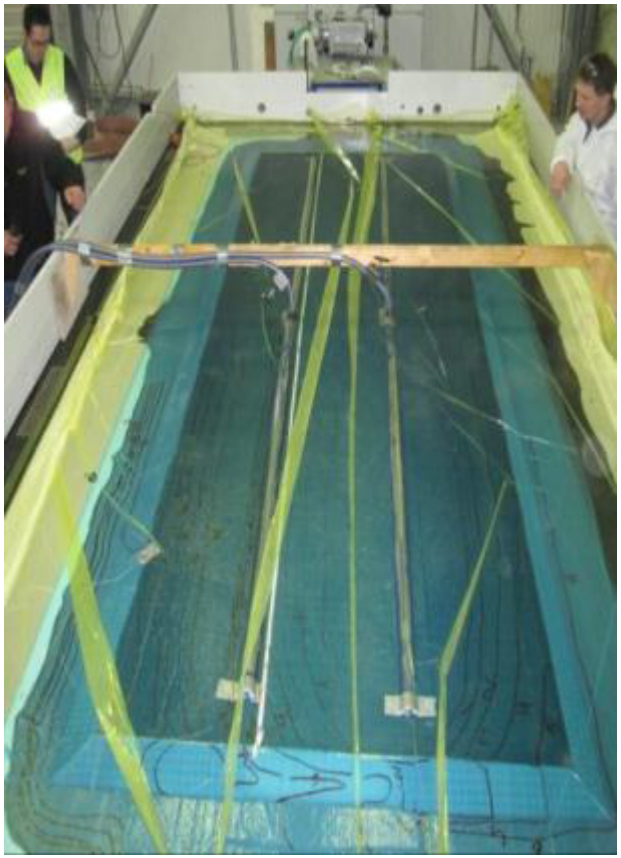
Foam and UD prepreg layers

Co-infusion: Case Study, Infusion Process

1 min



12 min



22 min

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

Co-infusion: Case Study, Demoulding

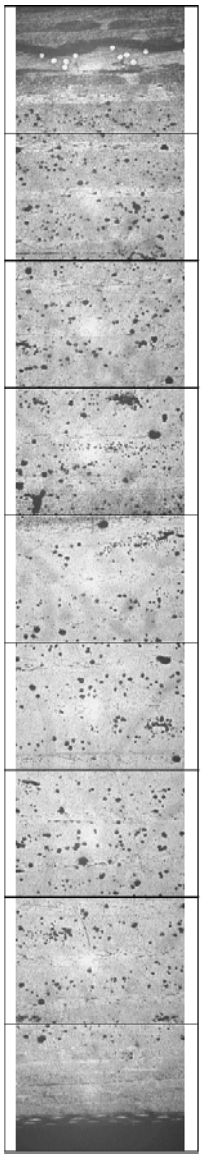
Full impregnation of the laminate

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

Co-infusion: Case Study, Porosity



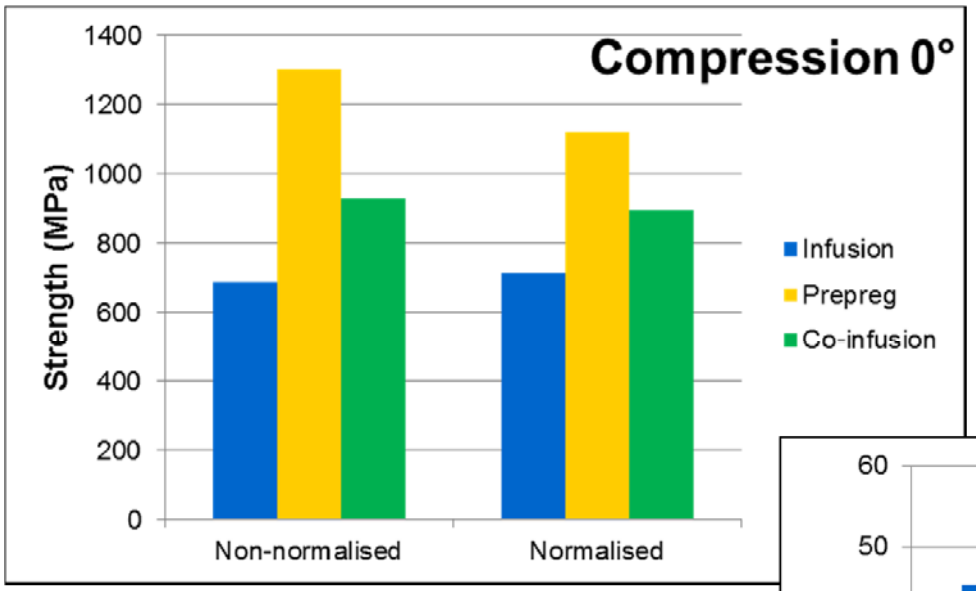
3x Infusion fabrics

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

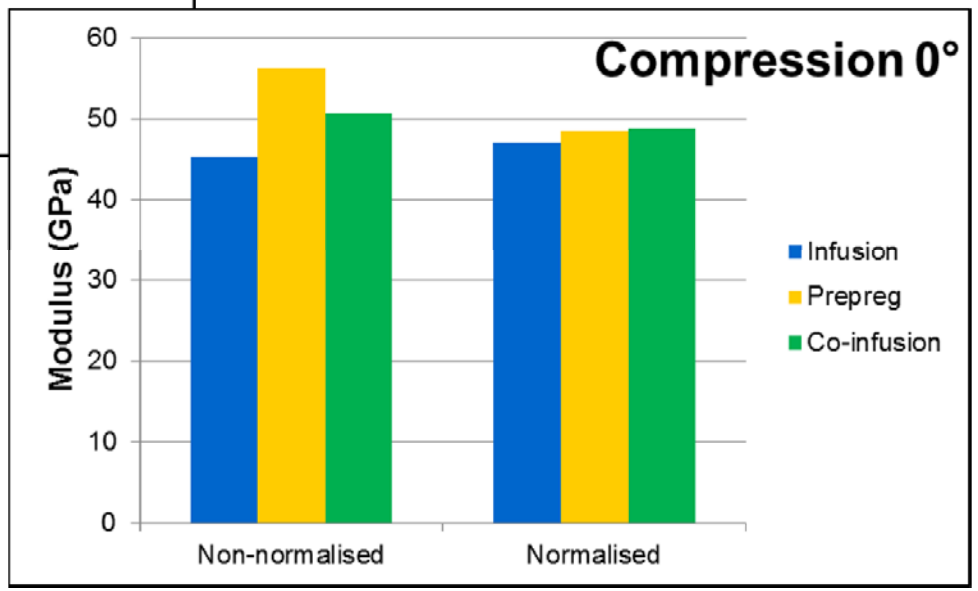
3x Infusion fabrics

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

Co-infusion: Case Study, Compression



* ISO 14126



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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