Improved Materials and Processes for Wind Turbine Blades

by Chris Shennan

29 March 2012

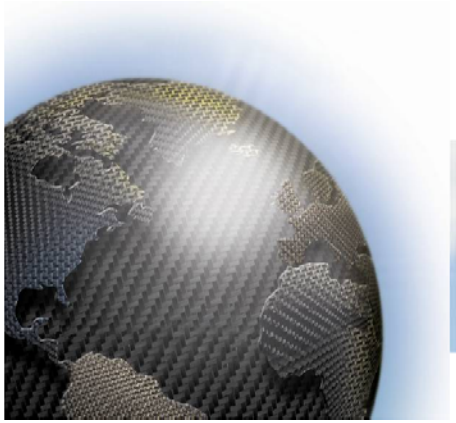
JEC Wind Energy Forum

Agenda

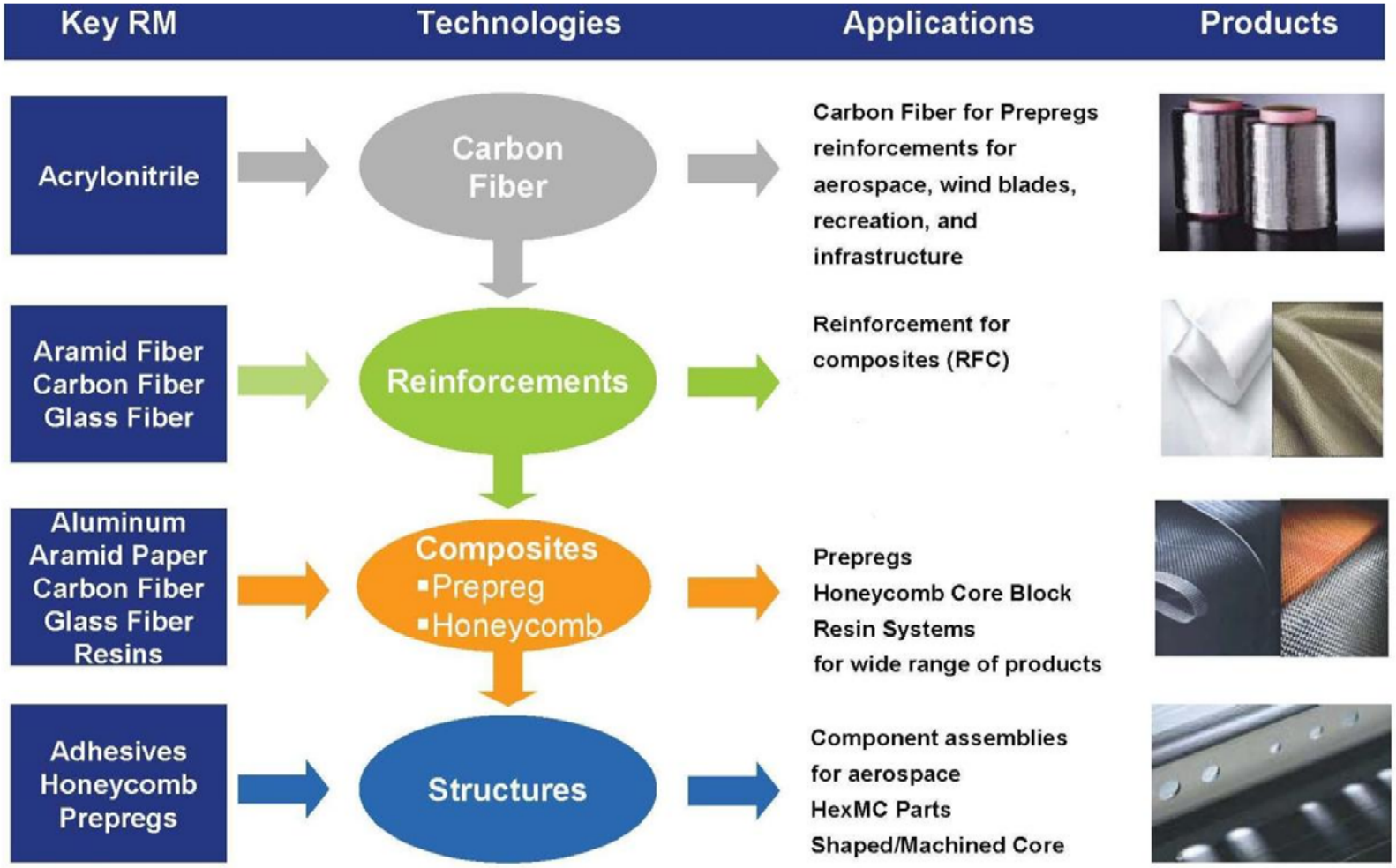
- **Introduction to Hexcel**
- **Prepreg technology**
- **Prepregs for the surface**
- **Prepregs for the load-carrying structure**
  - Comparisons between infusion and prepreg technologies
- **Use of prepregs for construction of spar caps**
  - Conventional, pre-cured
  - New: co-infused and co-cured
- **Conclusions**

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 - Vertically Integrated



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 Technology

What are ‘prepregs’?

Impregnation of Fibre and Fabrics with Resin

Prepreg production is now highly industrialised for optimum cost and quality

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

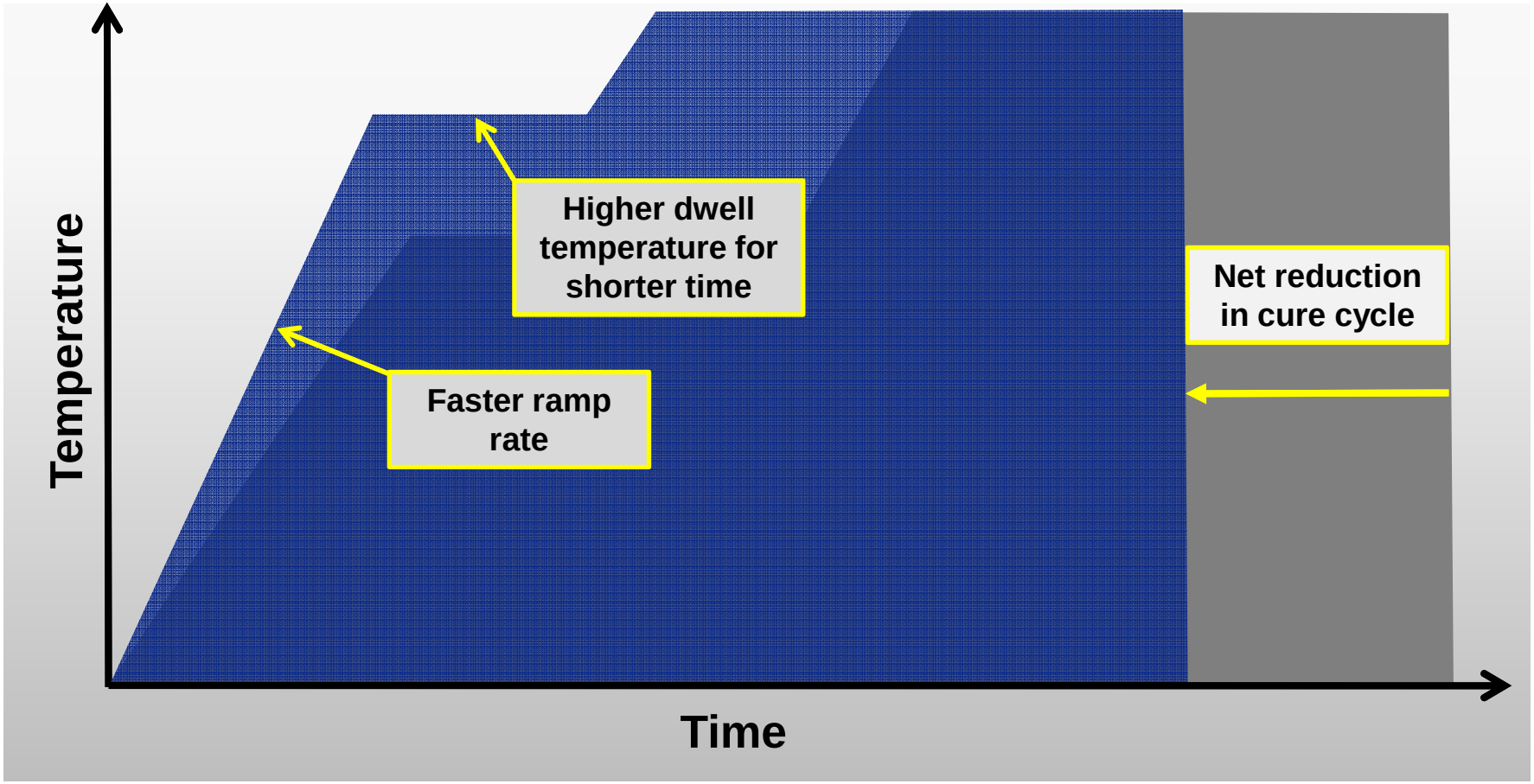
Storage	
Temperature	Shelf life
+23°C	6 weeks
+5°C	6 months
-18°C	18 months

Overall cure cycles

~4 to ~8 hours (optimisation is key)

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

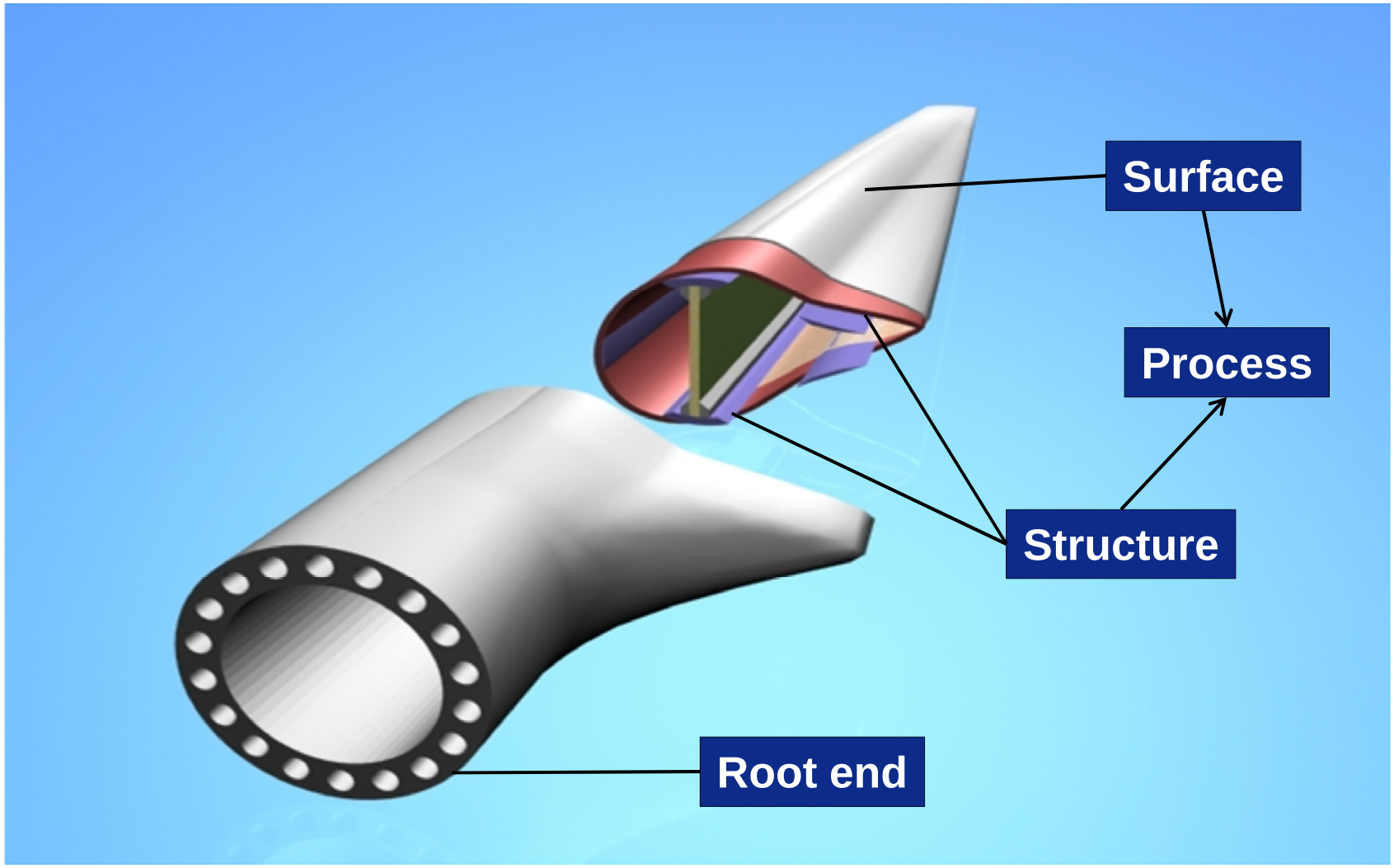
The Value of Low Exotherm in Thick Parts



Low exotherm matrix e.g. M19G

Standard exotherm matrix e.g. M9G

Major Features of Typical Wind Turbine Blades



Prepregs for the Surface

Prepregs for the Shell Surface

Shell prepregs are used for the aerodynamic shell

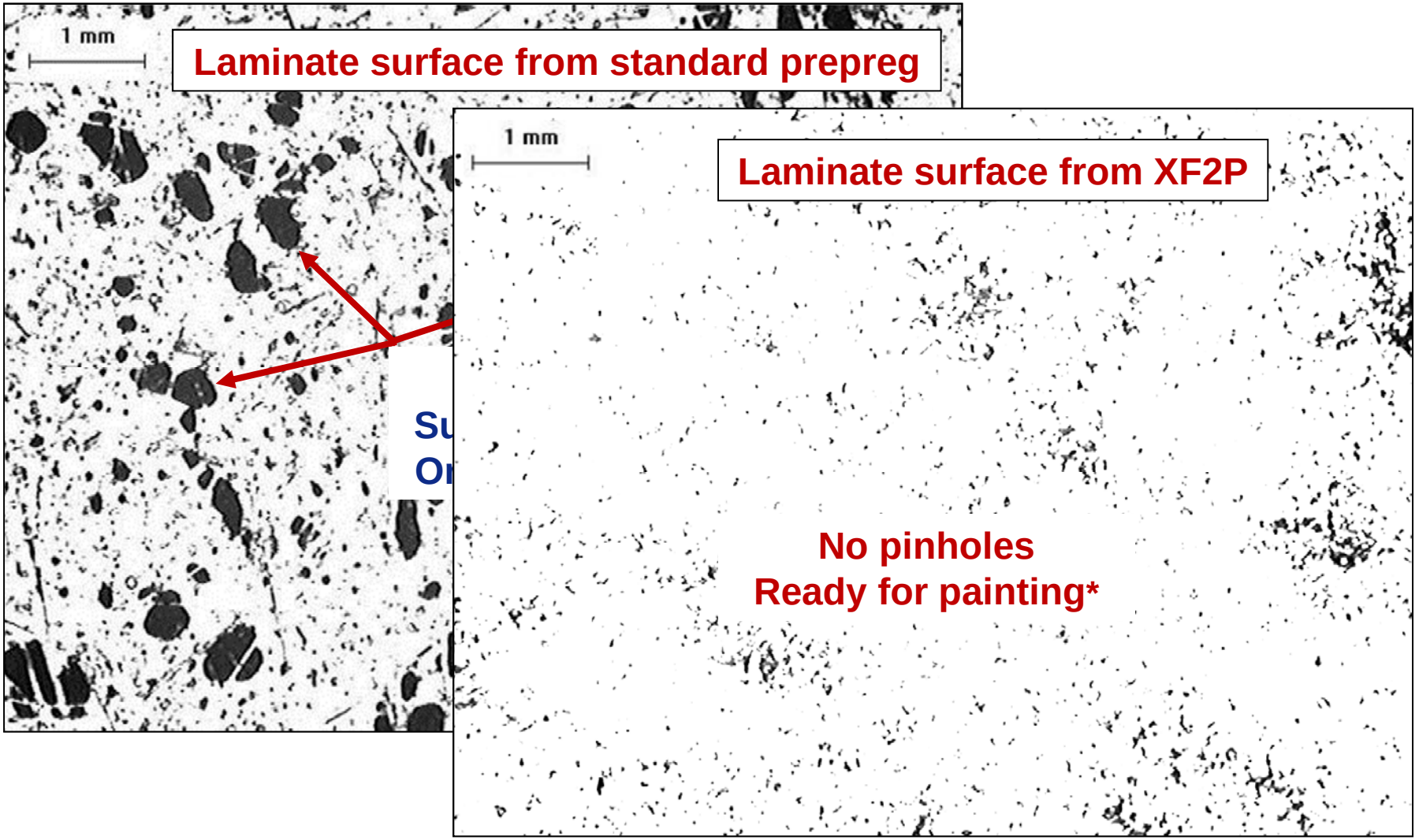
- Gel coats may be used to provide a good paint-ready surface
- Polyurethane paints may be used for the final surface

This process can be simplified by using specific shell prepregs

e.g. Products such as XF2P

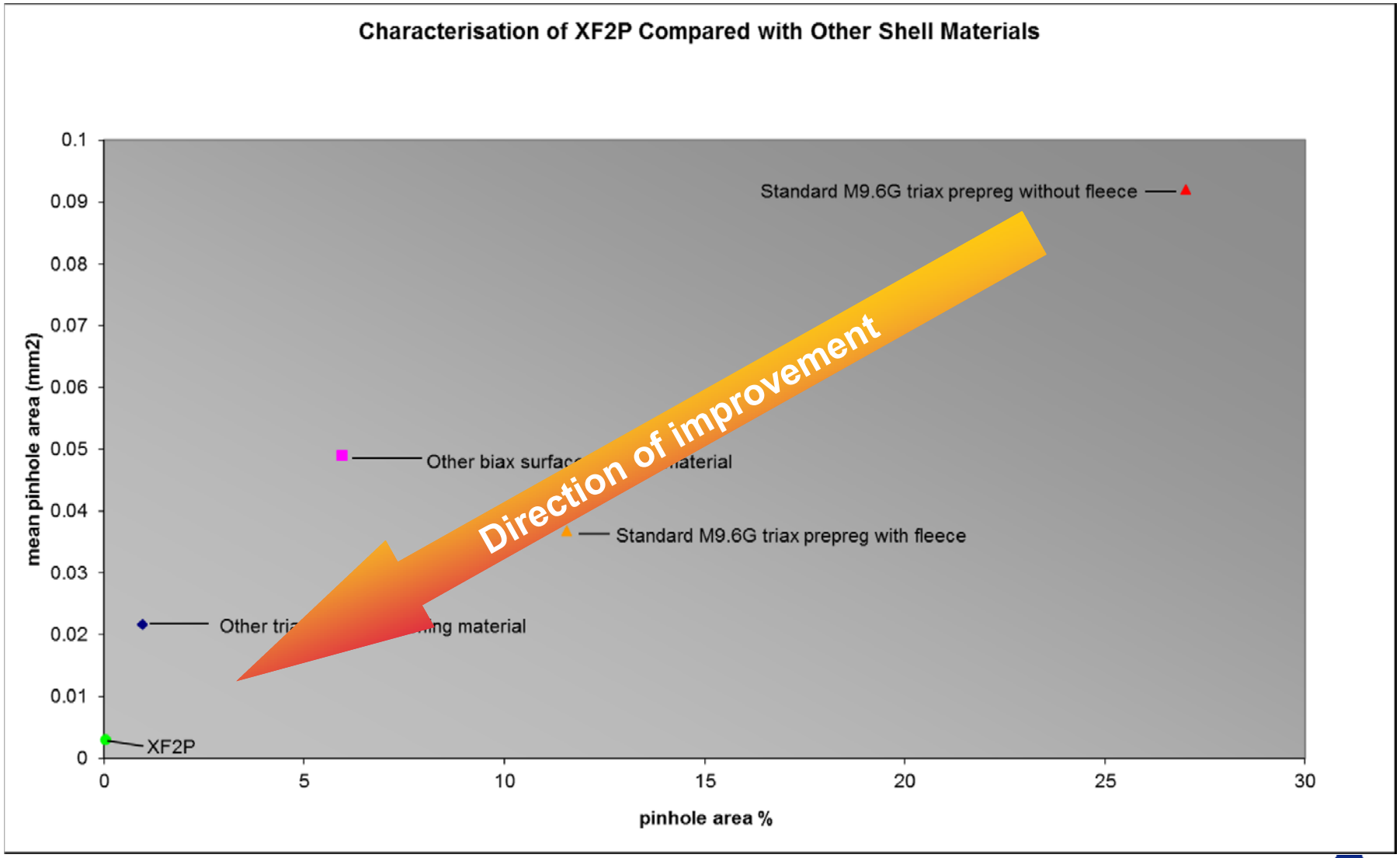
- Build the aerodynamic shell surface
- Eliminate the gel coat

XF2P: Surface Characterisation

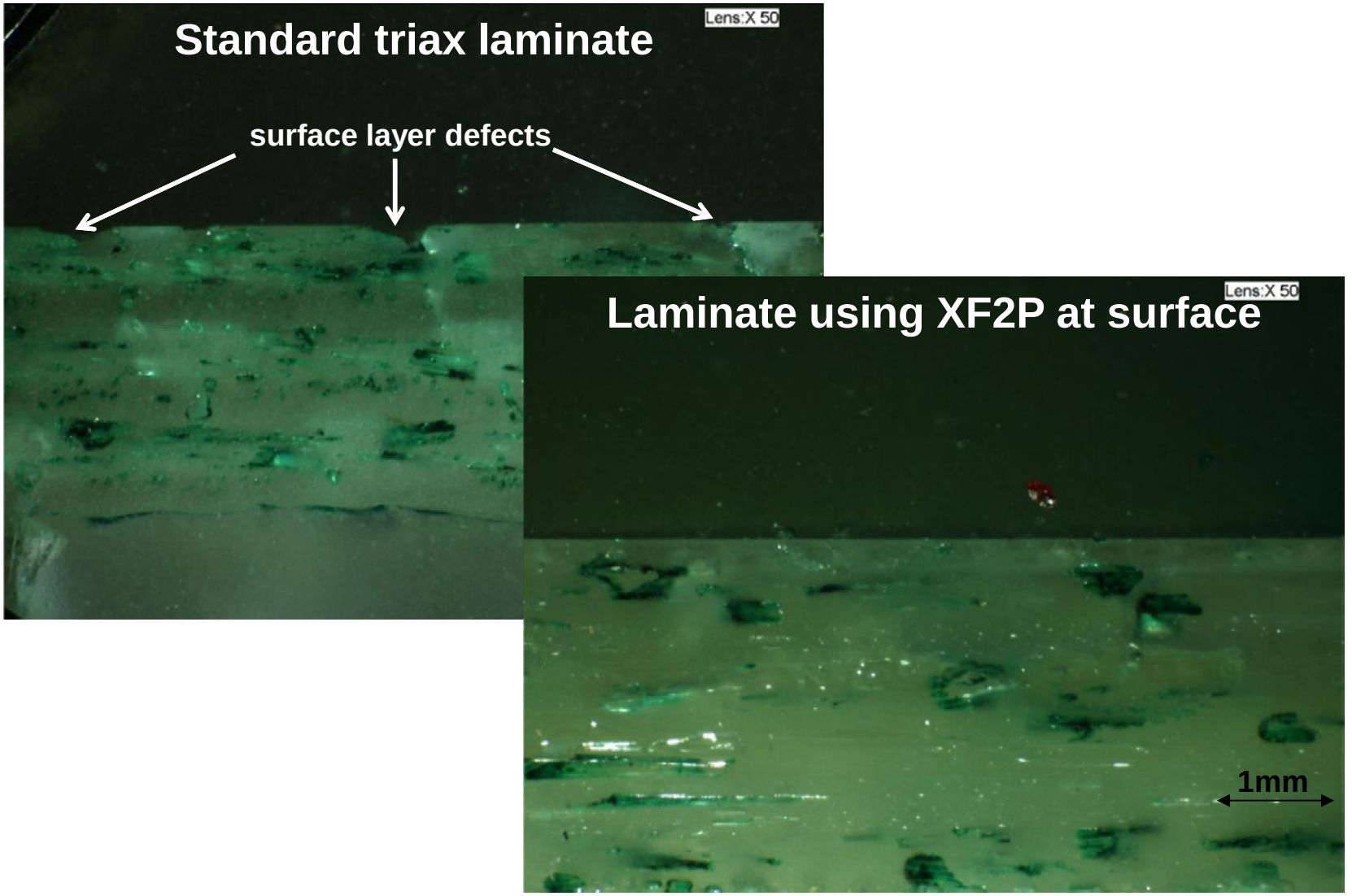


* After removal of release agent

Surface Porosity from Shell Materials



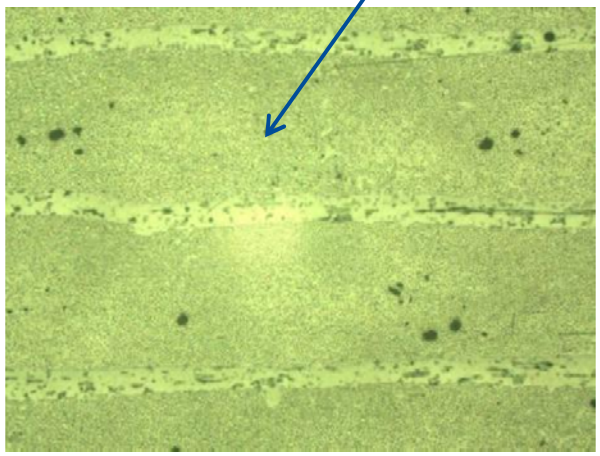
XF2P: Cross-sectional Analysis

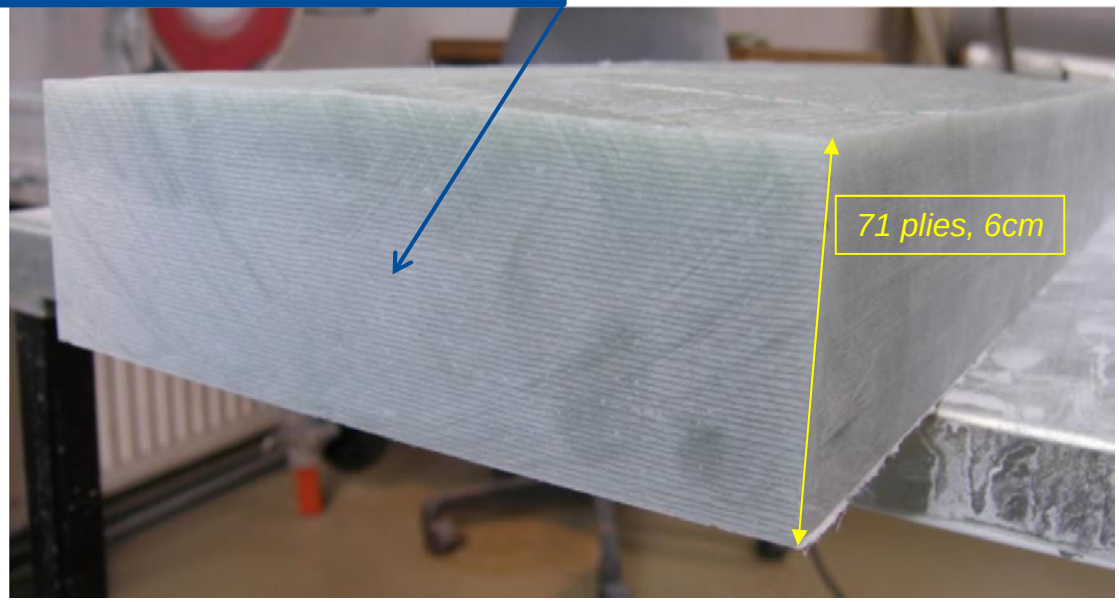


Prepregs for the Load-carrying Structure

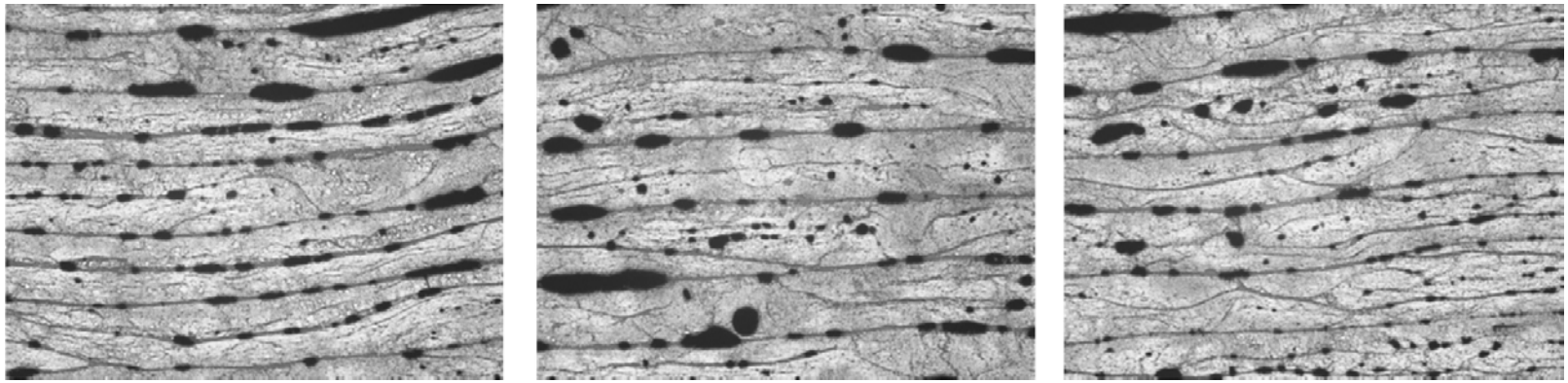
Thick Glass Laminates using Prepregs

Very low porosities from typical glass prepregs even in thick laminates





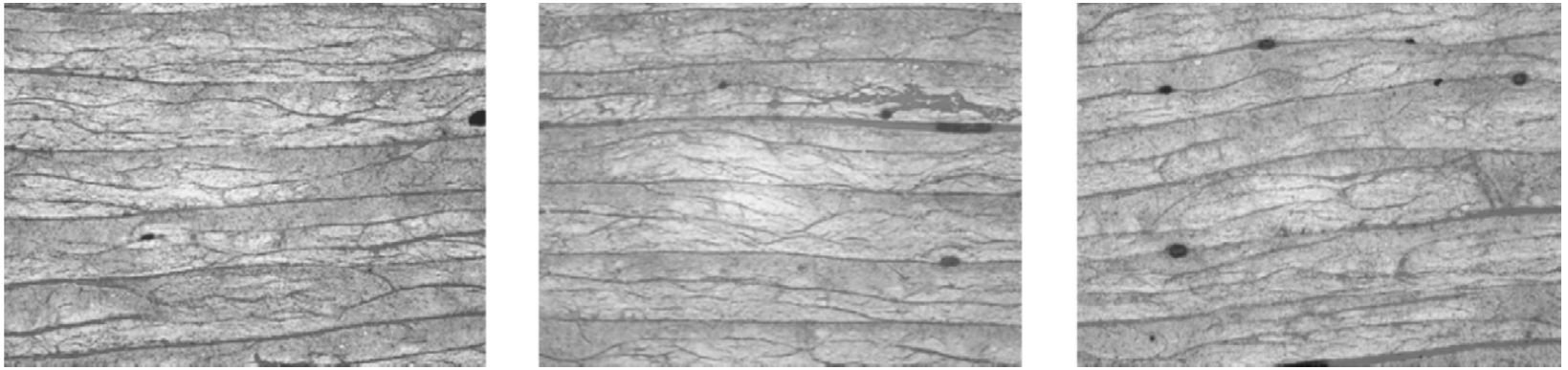
Thick Carbon Laminates – Conventional Technology



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 patented technology**
Porosity <<1%

Optimised architecture in carbon UD prepregs consistently minimises low porosity

Prepreg and Infusion Mechanical Properties

Glass

Glass: Materials

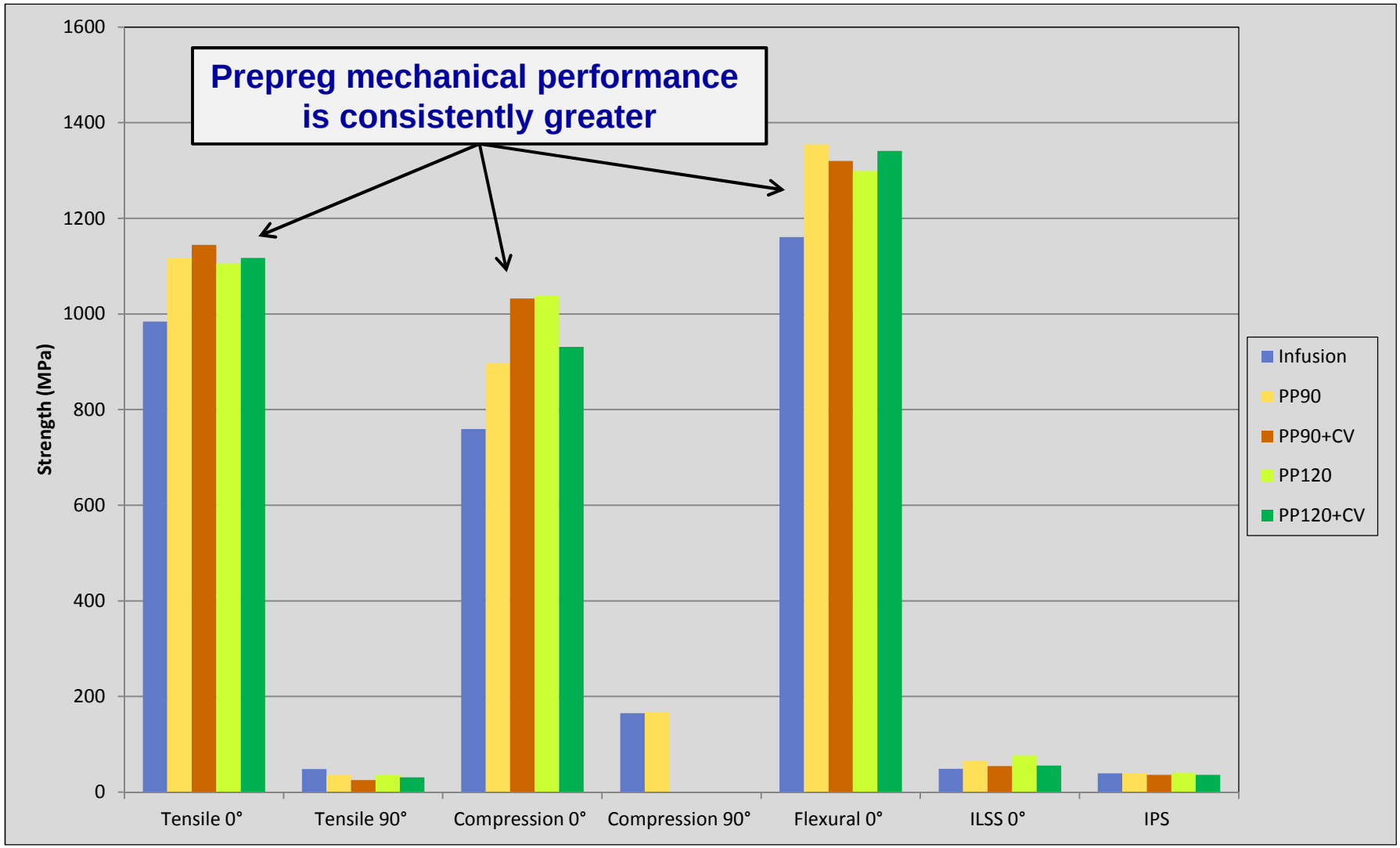
Infusion

- Reinforcement: LT1218 (UD1200 + slight reinforcement in 90°)
- Resin: Epikote RIM 135
- Cure at 90°C

Prepreg

- M9.6GLT/32%/1200(+CV)/G
- Cure at 90°C ('PP90') and 120°C ('PP120')

Glass: Mechanical Properties



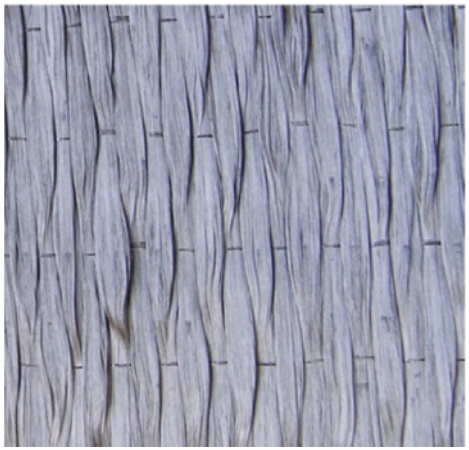
Prepreg and Infusion Mechanical Properties

Carbon

Carbon: Materials

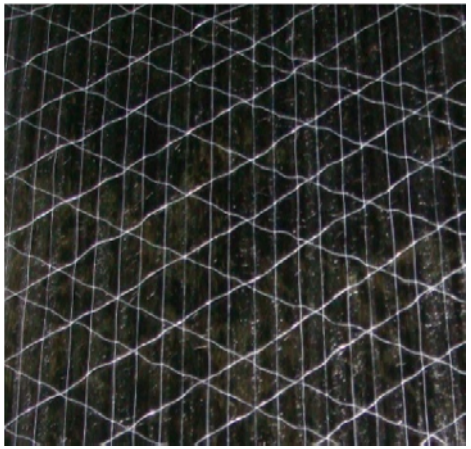
Infusion

- Reinforcement: UD600 low crimp T620
- Resin: Epikote RIM 135
- Cure at 90°C

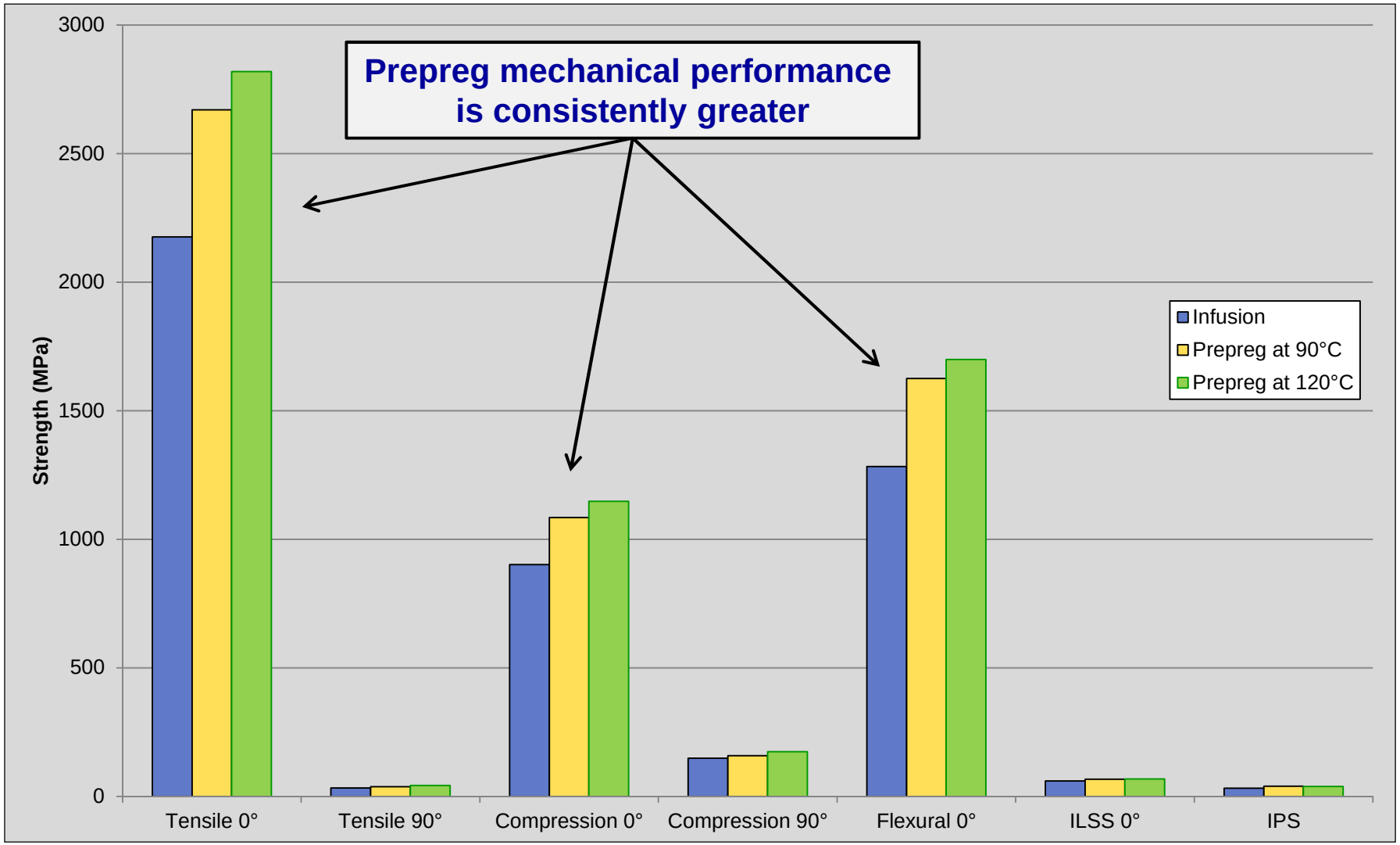


Prepreg

- M9.6GLT/35%/UD600+2P/T620+PES
- Cure at 90°C and 120°C



Carbon: Mechanical Properties

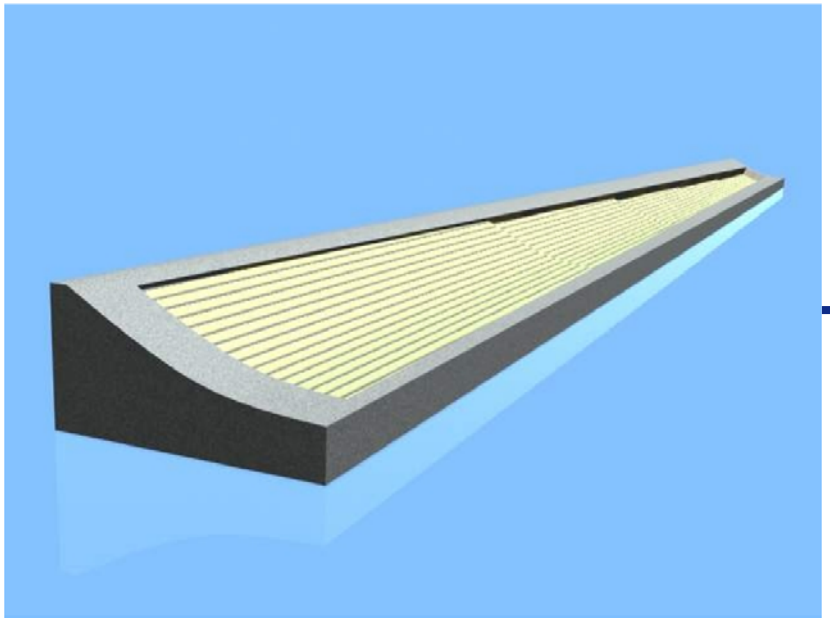


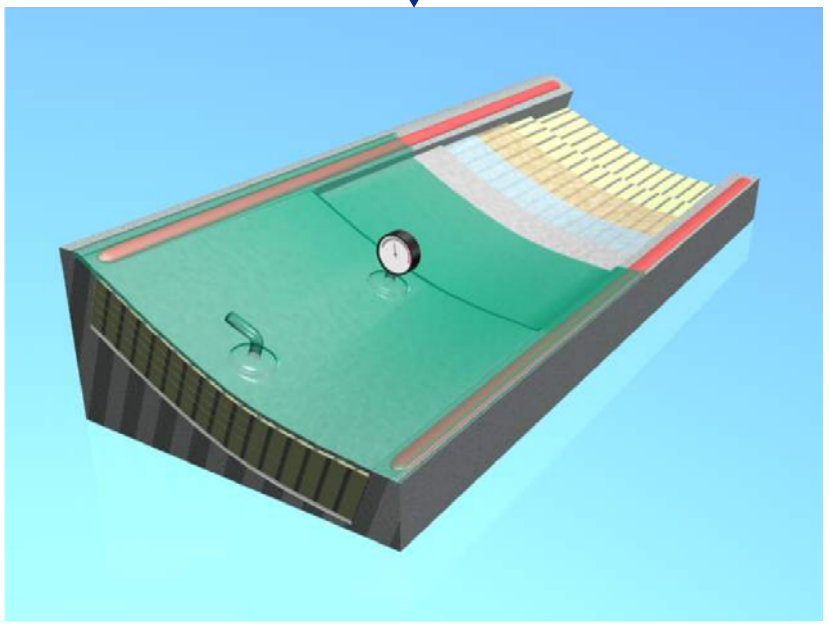
Use of Prepregs for the Construction of Spar Caps

Example 1

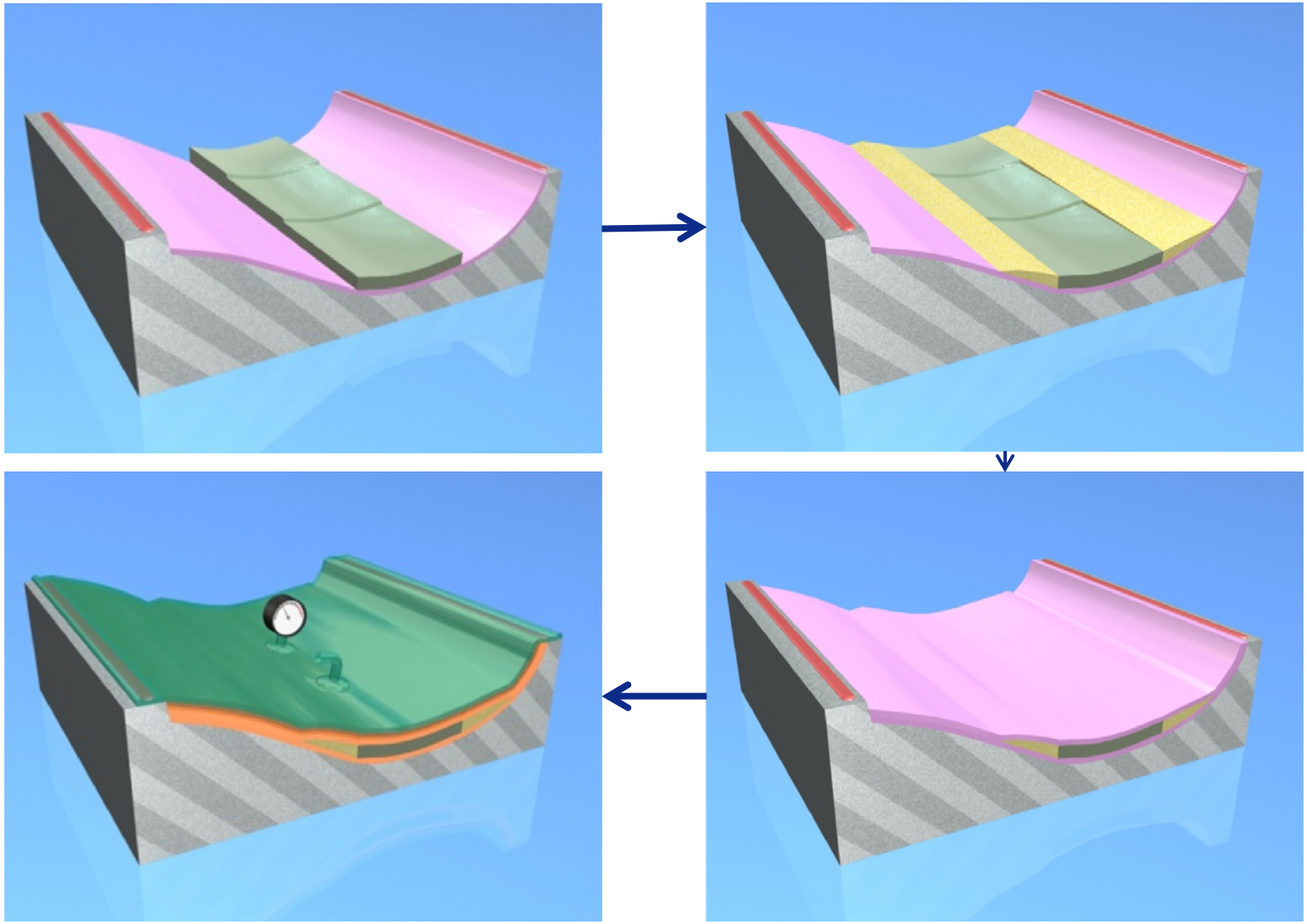
Pre-cured Spar Cap for Infusion and Final Cure

Spar Caps: Prepreg Layup and Cure



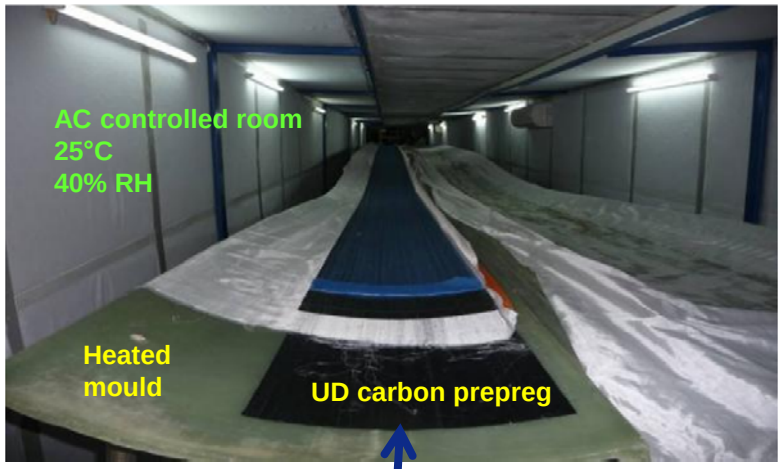


Spar Caps: Inclusion in an Infused Shell

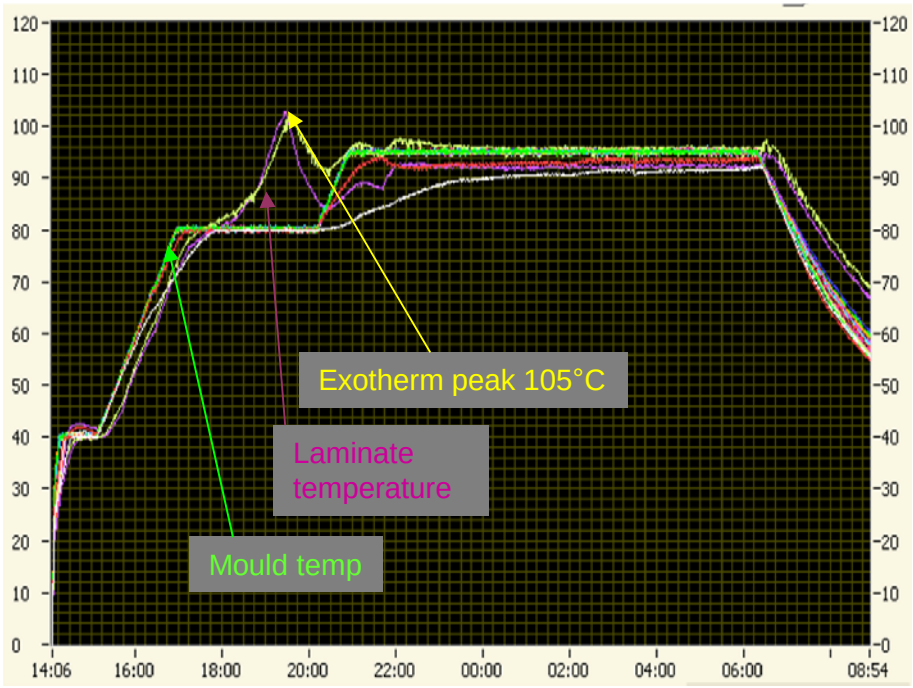


Case Study: Carbon Spar Cap at Half Scale

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

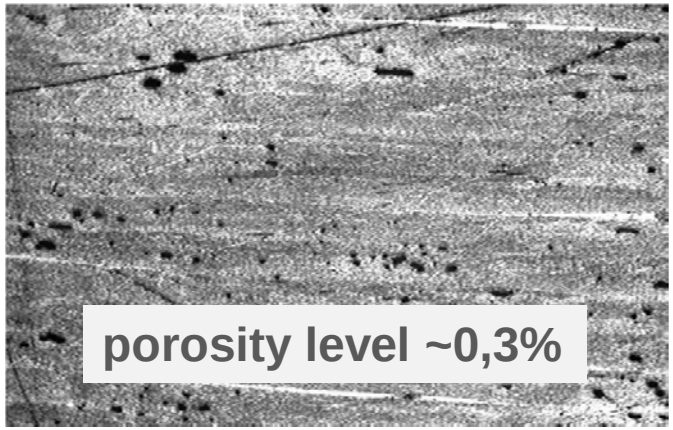


UD prepregs are ideally suited to automated layup



Case Study: Results

Spar cap Tg	**106°C**	
Average porosity	**0,24%**	
Highest porosity value	**0,8%**	**(1/135 points)**
Lowest porosity value	**0%**	**(19/135 points)**
Resin content	**30%**	



Typical cross section of cured laminate

Good adhesion of infused glass on prepreg carbon laminate

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

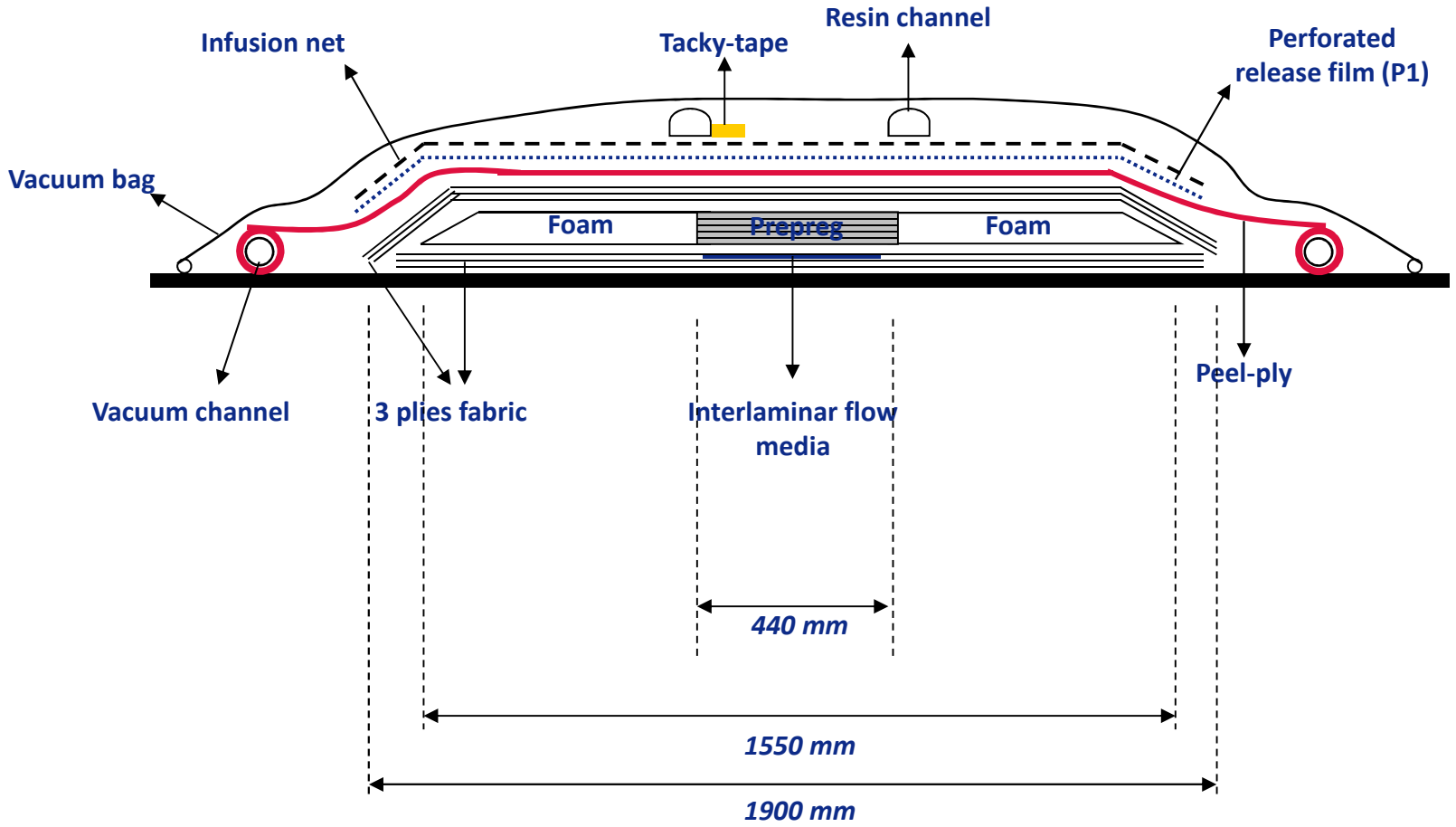
The use of prepreg and infusion technologies in the same laminate with co-cure

Typical configuration

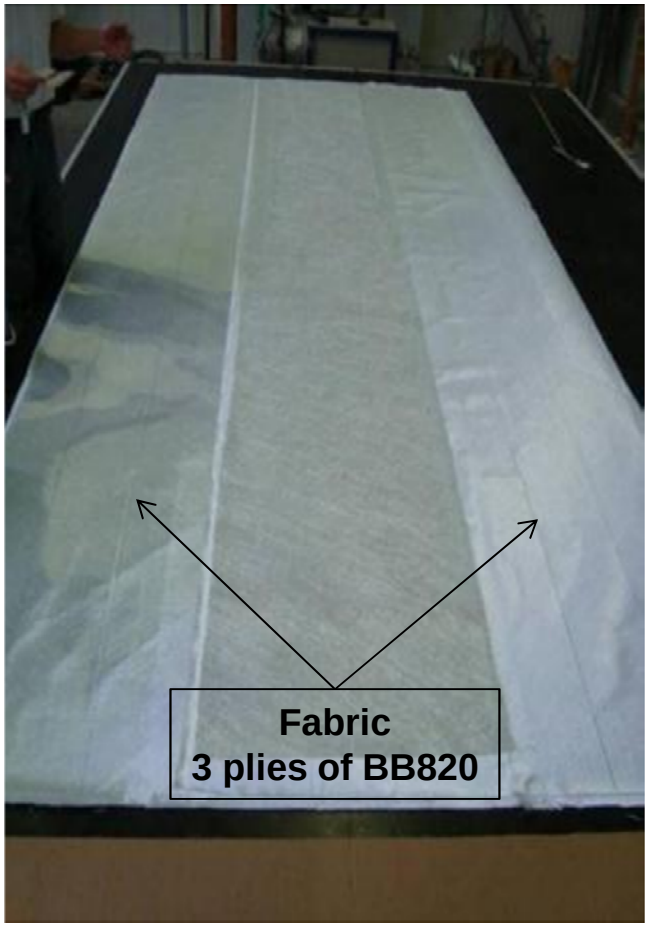
UD prepreg for the heavy load-carrying structure
Infusion of dry reinforcement for the remainder of the structure
Cure of the whole assembly at the same time and temperature

Co-infusion: Case Study, Construction

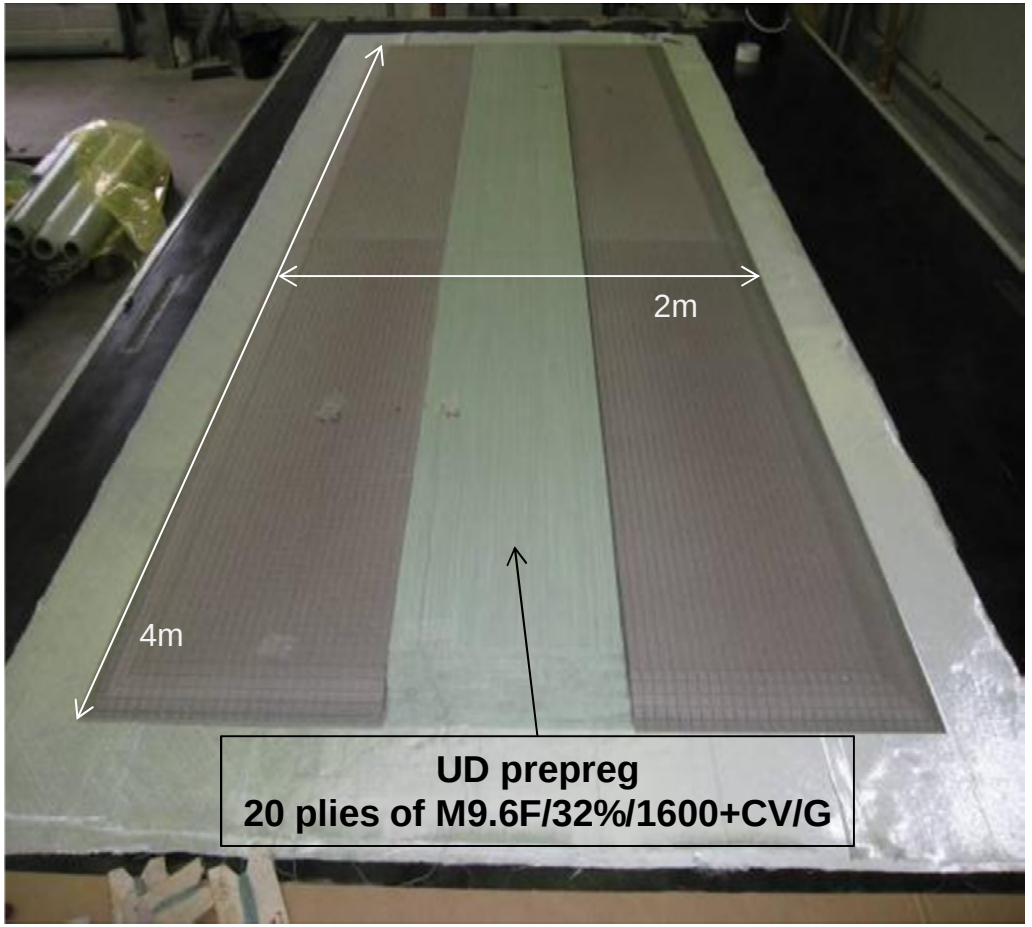
Demonstration on a 4 x 2m scale
UD prepreg with biax dry fabrics



Co-infusion: Case Study, Layup



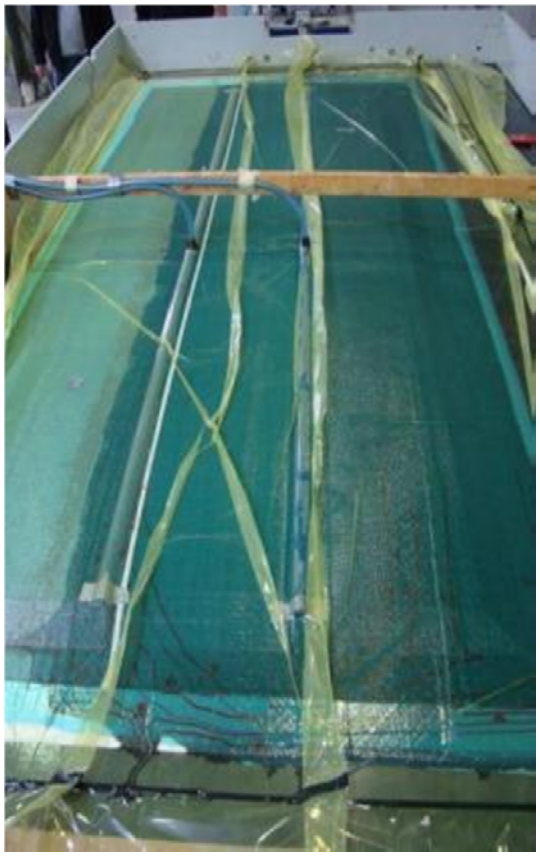
Dry reinforcements



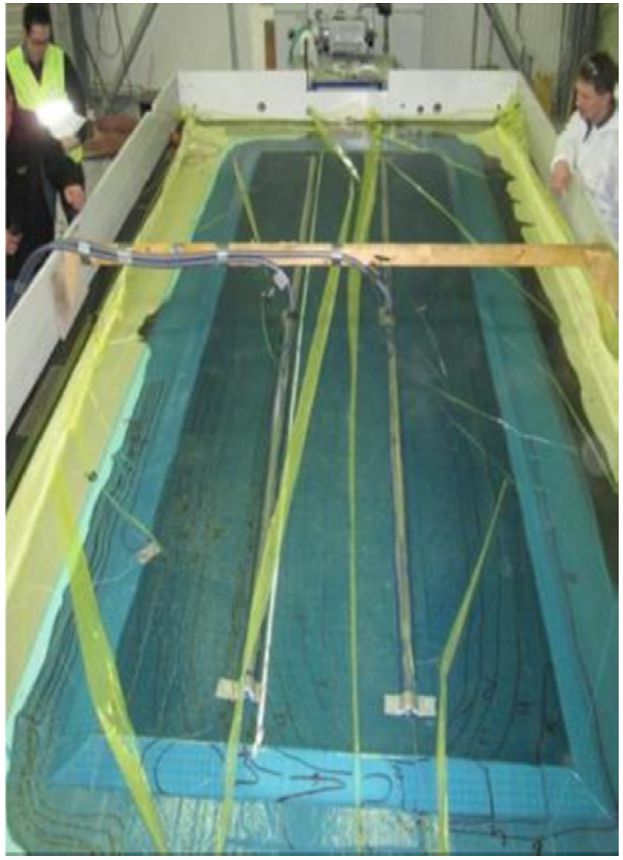
Foam and UD prepreg layers

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

Conclusions

Prepregs can be tailored for optimal wind blade manufacture

- **Lowest exotherm from matrix selection**
- **Shortest cure cycle from fast cure and low exotherm**
- **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

Disclaimer

This document and all information contained herein is the sole property of HEXCEL CORPORATION. No intellectual property rights are granted by the delivery of this document or the disclosure of its content.

This document shall not be reproduced or disclosed to a third party without the express written consent of HEXCEL. This document and its content shall not be used for any purpose other than that for which it is supplied.

The statements made herein do not constitute an offer. They are based on the mentioned assumptions and are expressed in good faith. Where the supporting grounds for these statements are not shown, HEXCEL will be pleased to explain the basis thereof.