Carbon Fiber Composites in Wind Energy: Challenges and Solutions

Chris Shennan

27 August 2014

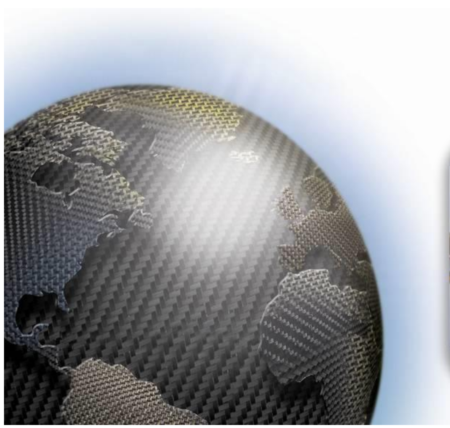
Sandia Wind Turbine Blade Workshop 2014

Agenda

- **Introduction**
- **Five challenges**
  - Control of porosity
  - Impregnation of fibre bundles by the matrix
  - Cure cycle of thick sections
  - Effect of fibre alignment on performance
  - Mechanical performance
- **Summary and conclusions**

Hexcel Company Profile

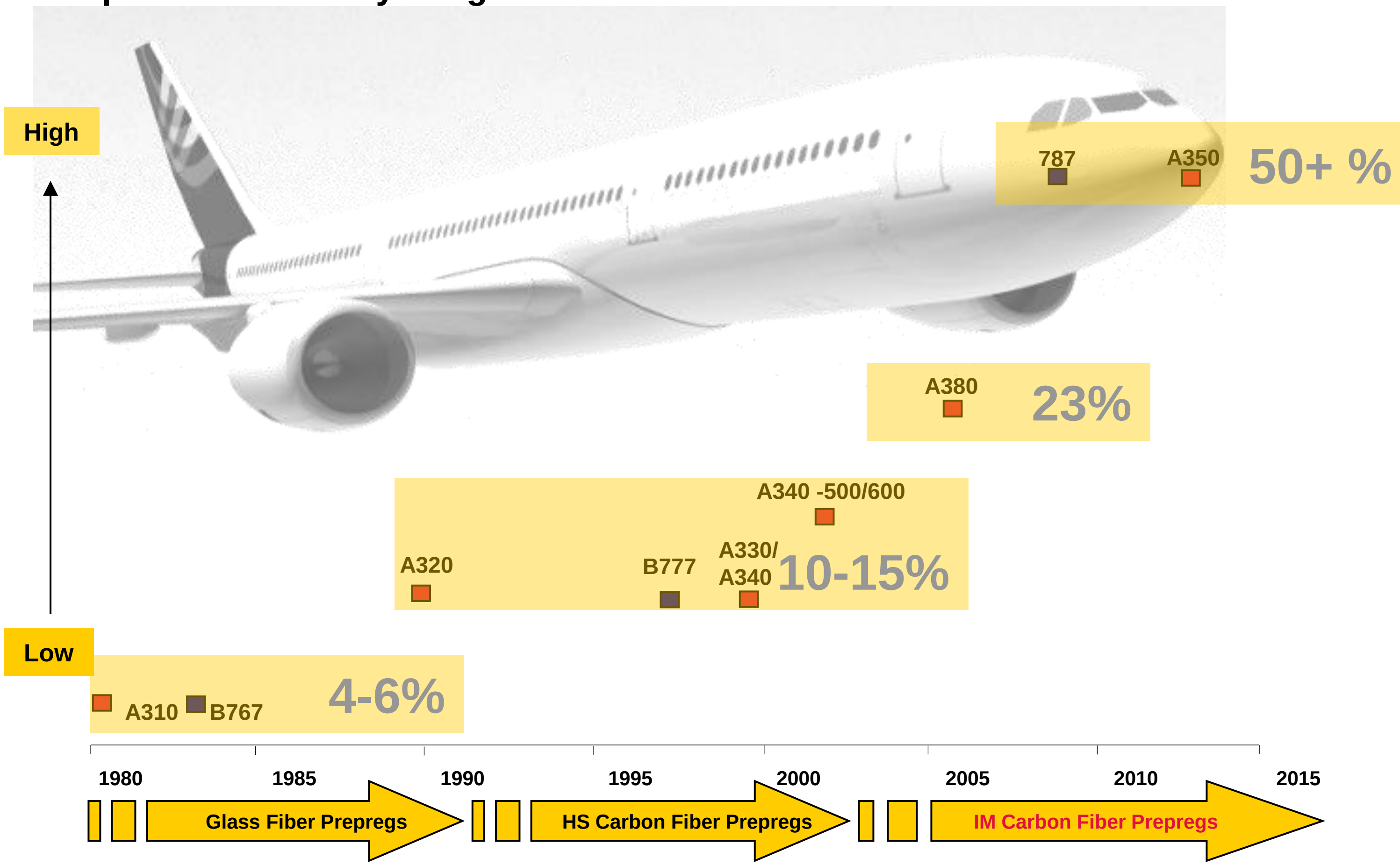
- Technology leader in advanced composites
- Serving commercial aerospace, space & defense and industrial
- Net Sales 2013: $1.68 Billion
- 5,300 employees worldwide
- 19 manufacturing sites (including JV in Malaysia)
- Headquarters in Stamford, CT, USA
- Listed on New York and Paris Stock Exchanges



HEXCEL®

Commercial Aerospace – Composites Penetration

Composite Content by Weight



New designs are more composite intensive

HEXCEL®

Overall Blade Structure

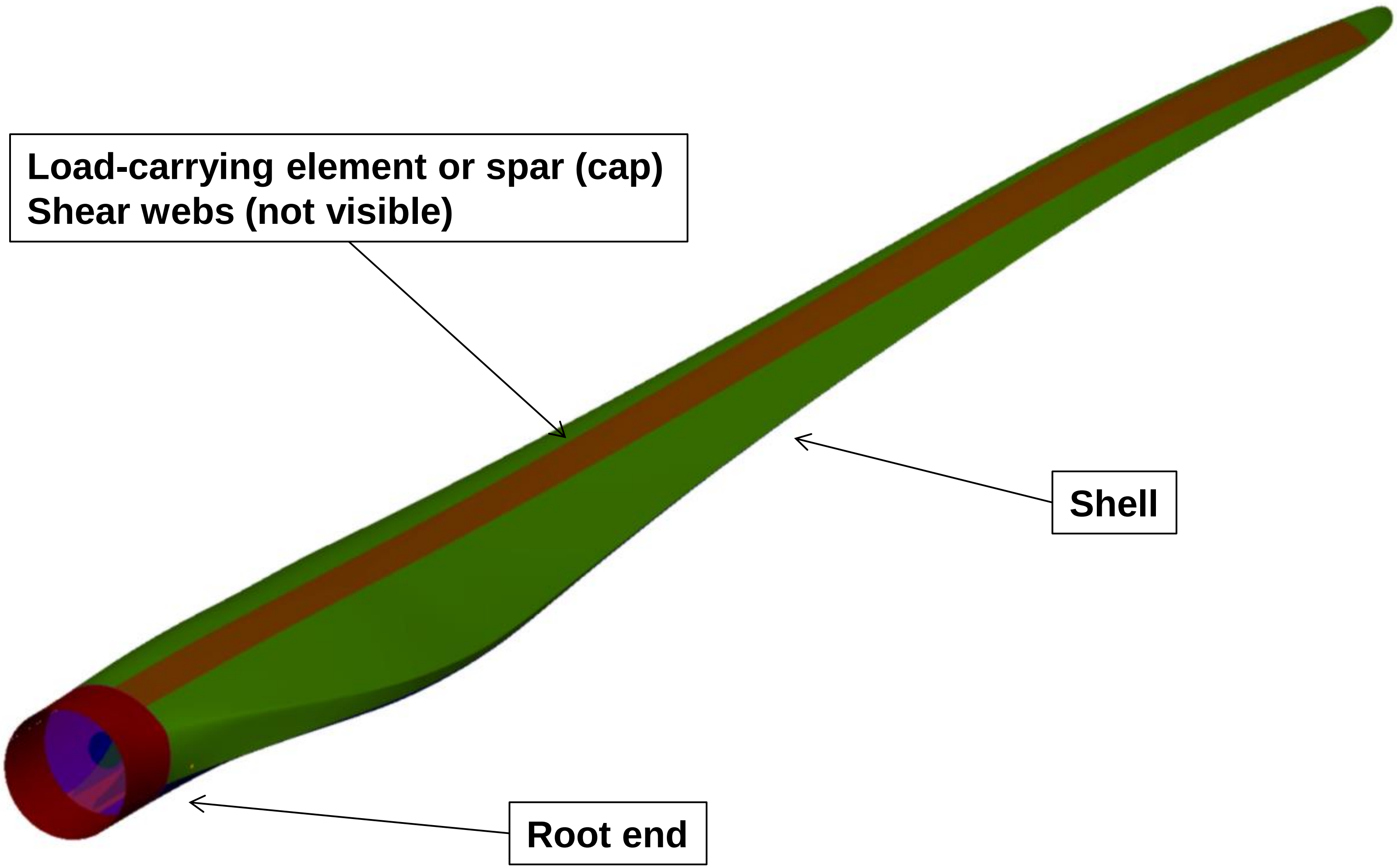


Image: © STRUCTeam Ltd

Summary of Blade Requirements

Blade element	Function	Performance requirements	Main driver
Root	a) Connect blade to hub b) Transfer loads from blade to hub	a) Highly loaded b) Provide space for bushings	*Cost versus performance*
Spar Cap	Structural integrity of blade	a) Provide stiffness b) Carry loads c) New materials	*Performance*
Shear web	Transfer shear forces between shells	Low to moderate	*Cost*
Shell	Aerodynamic efficiency	a) Surface quality b) Aerodynamic surface	*Cost*

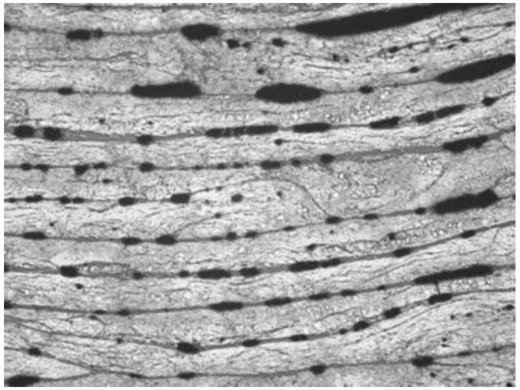
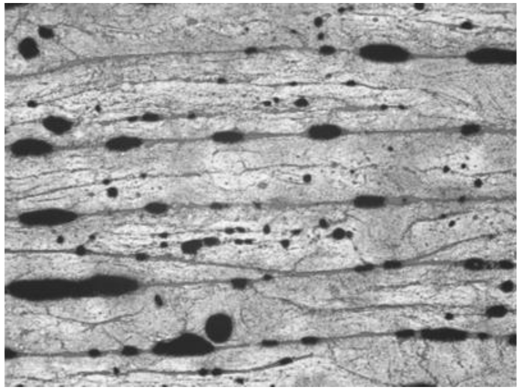
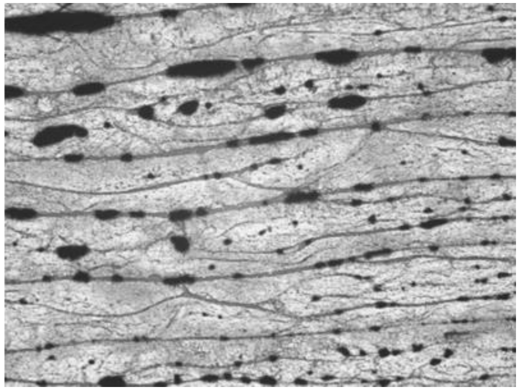
Different elements have drivers leading to requirements for different materials and processes
Focus here: spar cap, especially using carbon

HEXCEL®

Porosity Control

Effect of vacuum only cure on thick laminates

Thick Carbon Laminates – Conventional Technology

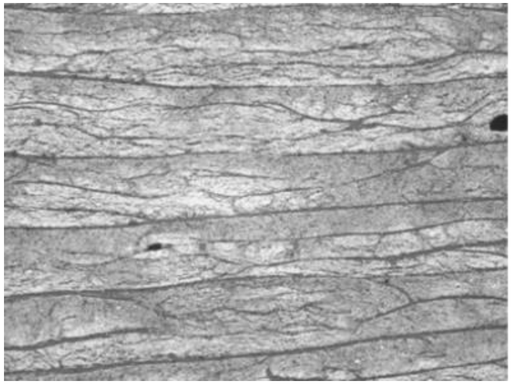




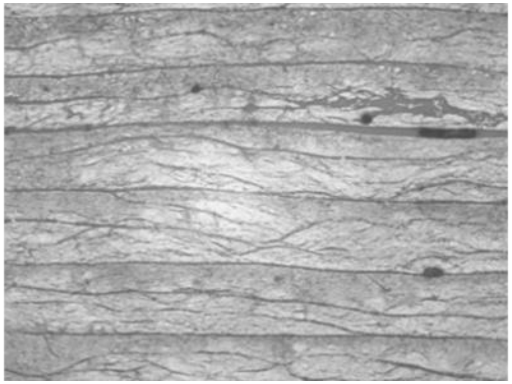
64 ply laminates using 600 g/m^2 carbon (HS) prepreg and conventional technology
Porosity ~7%

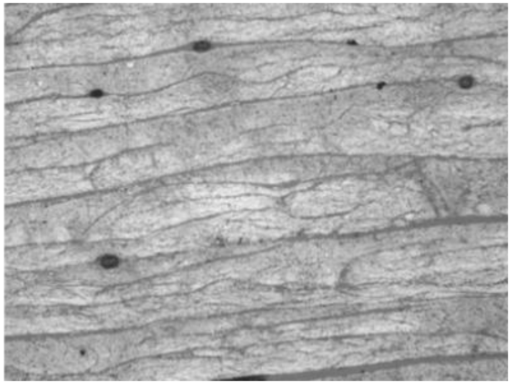
Conventional prepregs give best results in thin laminates and/or with autoclave cure

HEXCEL

Thick Carbon Laminates – Optimised Architecture







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

Layer uniformity can be further improved by optimising the stack sequence

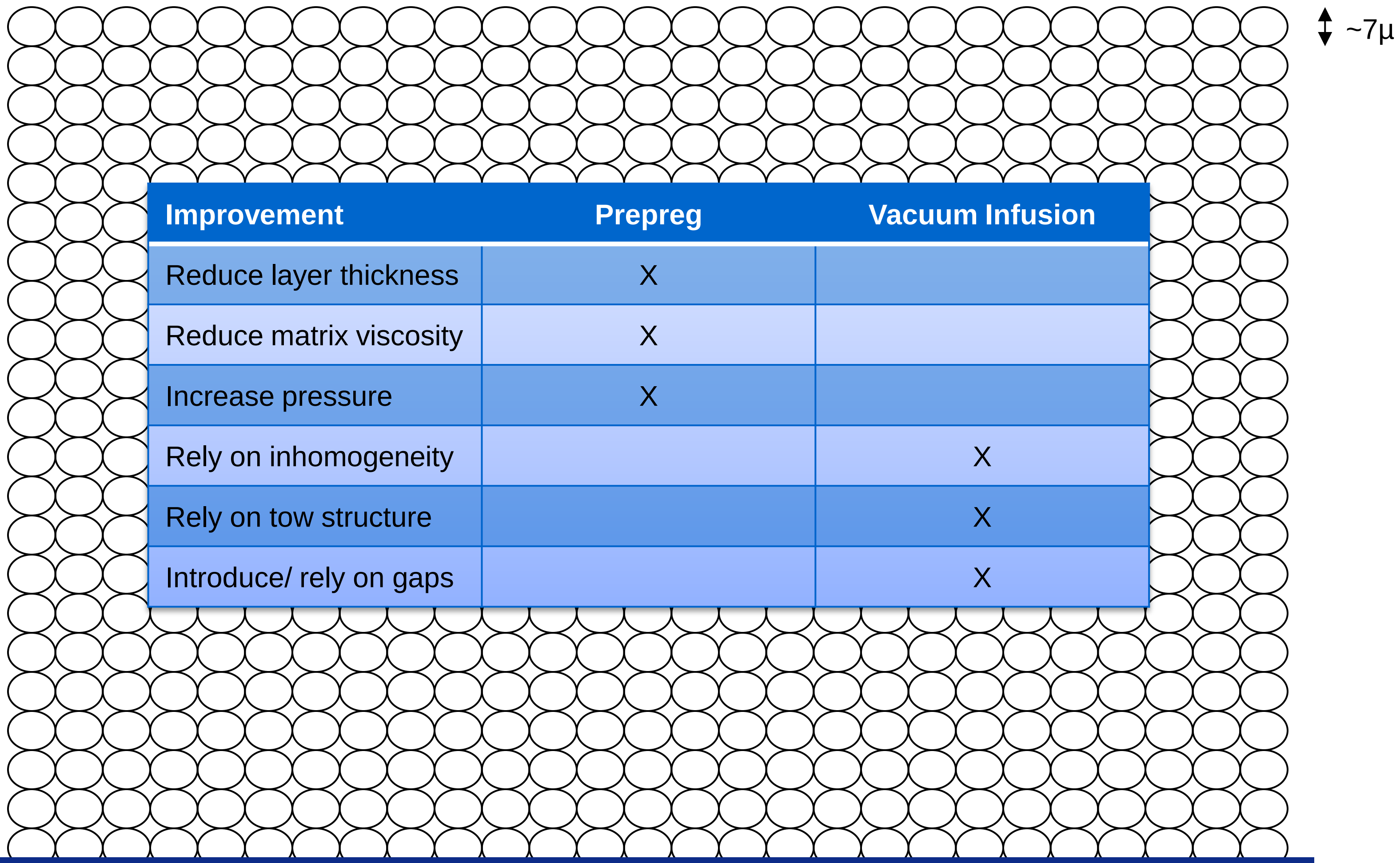
Thick laminates and vacuum only cure require a specific architecture for low porosity using carbon UD prepregs

HEXCEL

Matrix Impregnation of Carbon

Effect of Fibre, Diameter, and Packing

Impregnation of Pure UD Fibre



Improvement	Prepreg	Vacuum Infusion
Reduce layer thickness	X	
Reduce matrix viscosity	X	
Increase pressure	X	
Rely on inhomogeneity		X
Rely on tow structure		X
Introduce/ rely on gaps		X

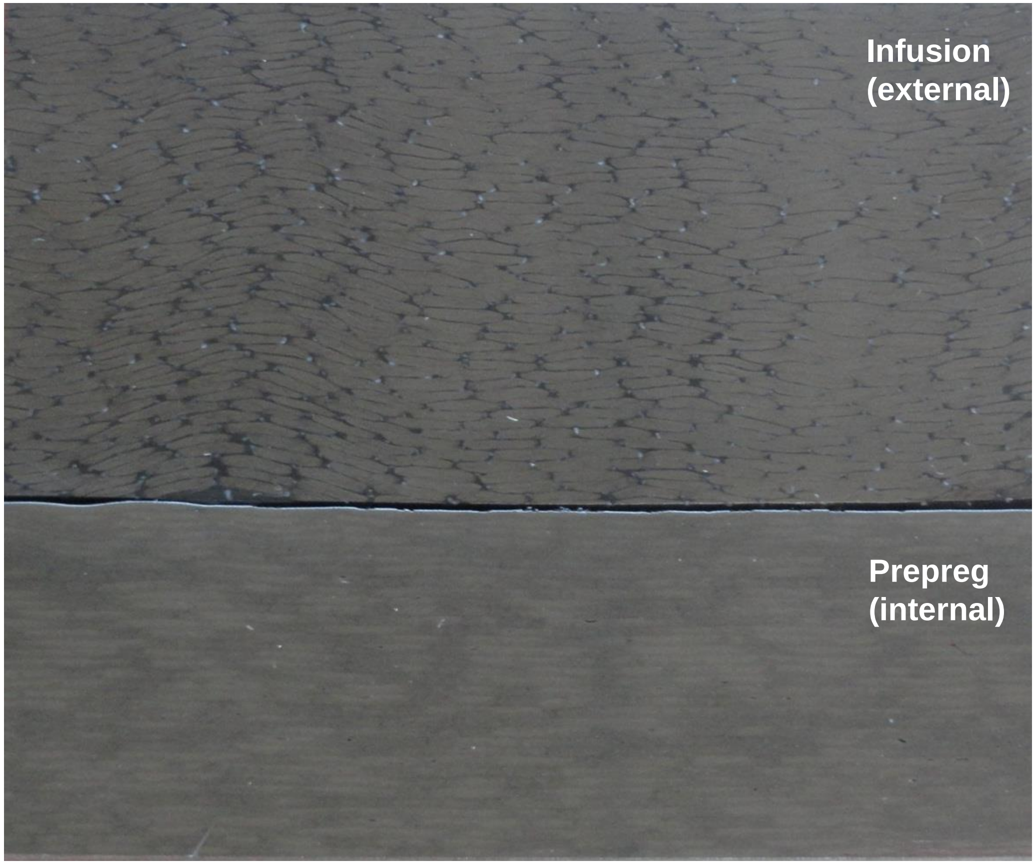
Prepreg and vacuum infusion rely on different approaches for successful impregnation

Optical Comparison: Infusion vs. Prepreg

Effect of morphology – infused carbon vs. carbon prepreg

- Porosity of infused part is lower

- Prepreg sample shows:
  - Uniform morphology of both fiber/matrix distribution and alignment
  - Greater homogeneity

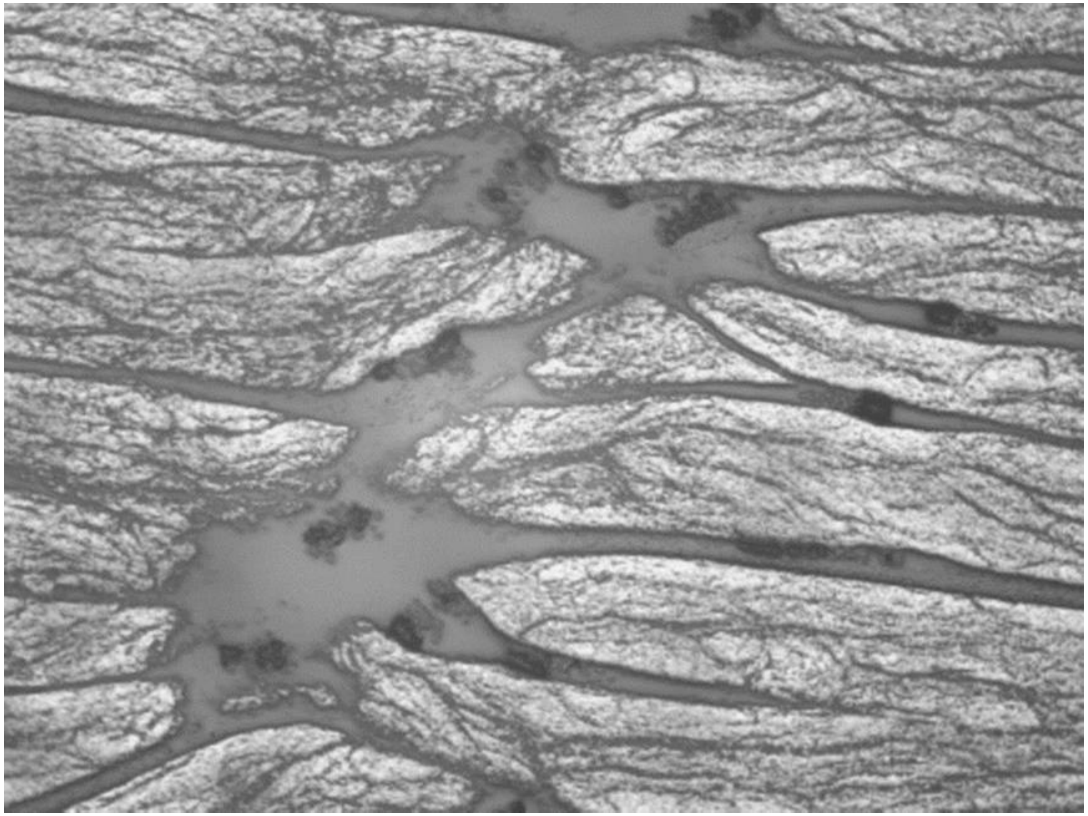


Prepreg sample shows good uniformity in X, Y and Z directions

Optical Comparison: Infusion vs. Prepreg

Infusion laminate: fiber/ matrix distribution

- Resin rich areas between fiber bundles are clearly evident in the infused carbon part

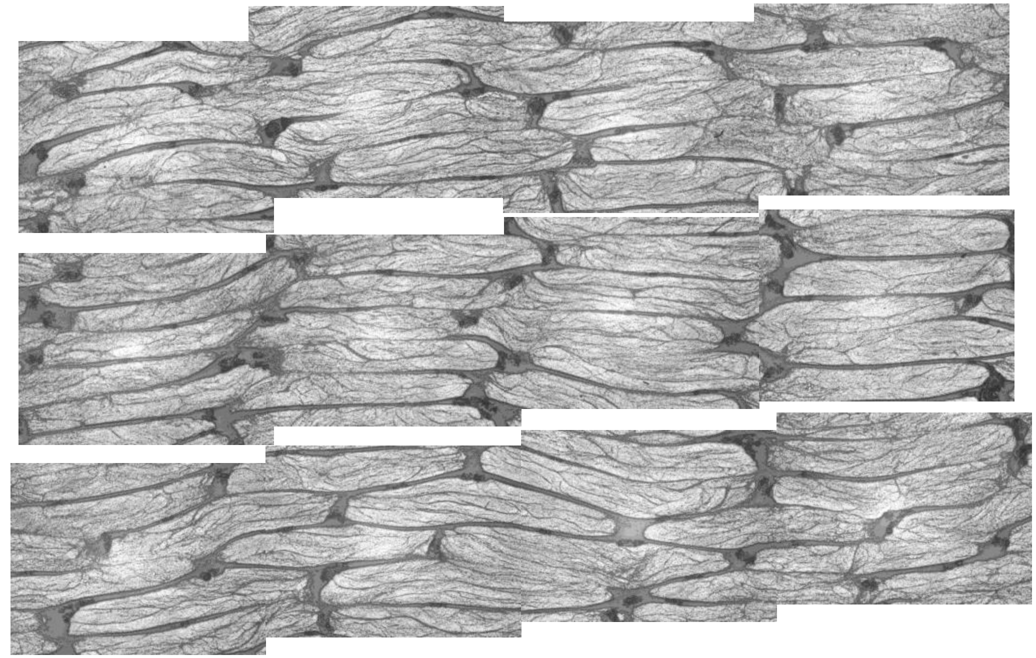


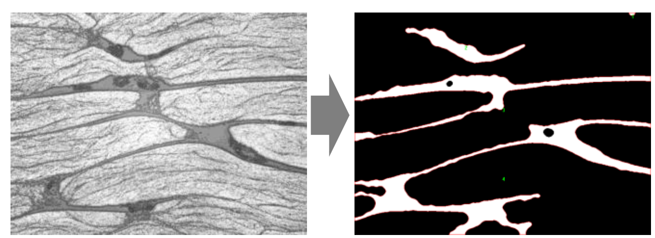
Non-uniformity of resin and fibre is a prominent feature of the infused laminate

Optical Comparison: Infusion vs. Prepreg

Infusion laminate morphology

- Distinct matrix boundaries between carbon fiber bundles
- Fiber and matrix rich areas result in fiber-volume variations over cross section
- Fiber bundles are deformed and possibly deflected in Z direction
- Porosity is generally low, but some bigger pores are present





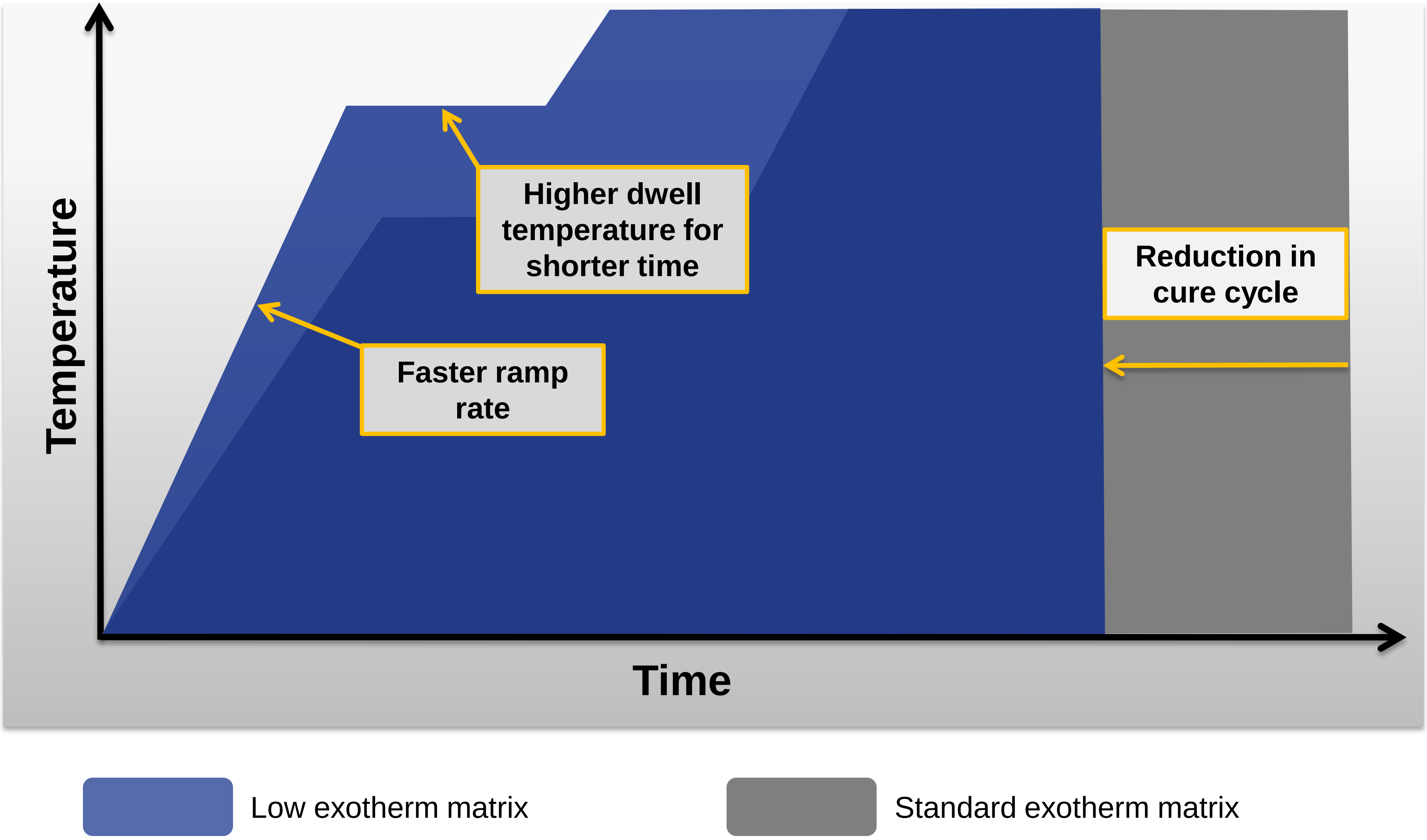
Matrix rich domains form ~15% of total

Infusion sample is less uniform: for fibre, fibre direction and matrix

Cure Cycle

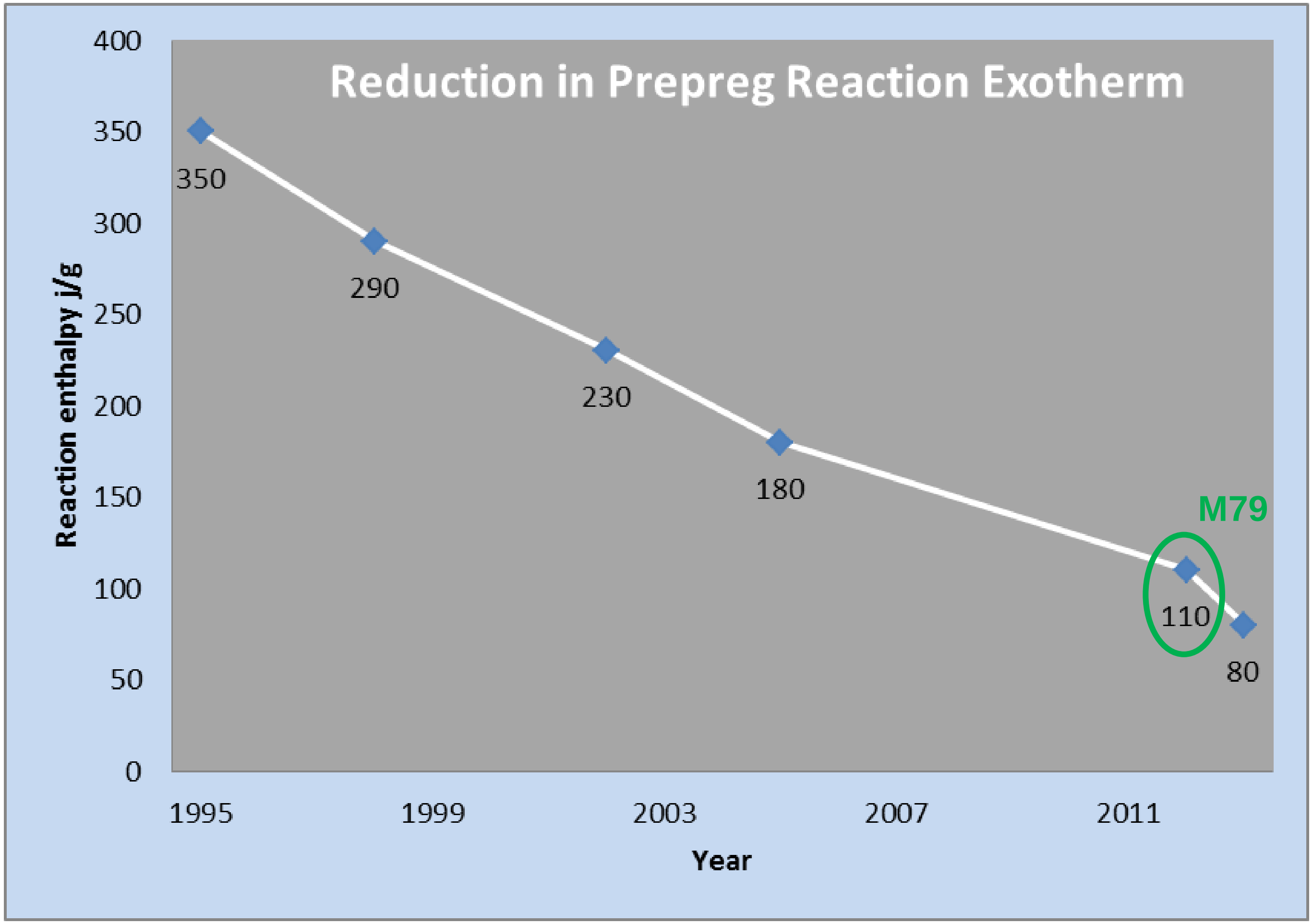
Effect of reaction exotherm

The Value of Low Exotherm in Thick Laminates



HEXCEL

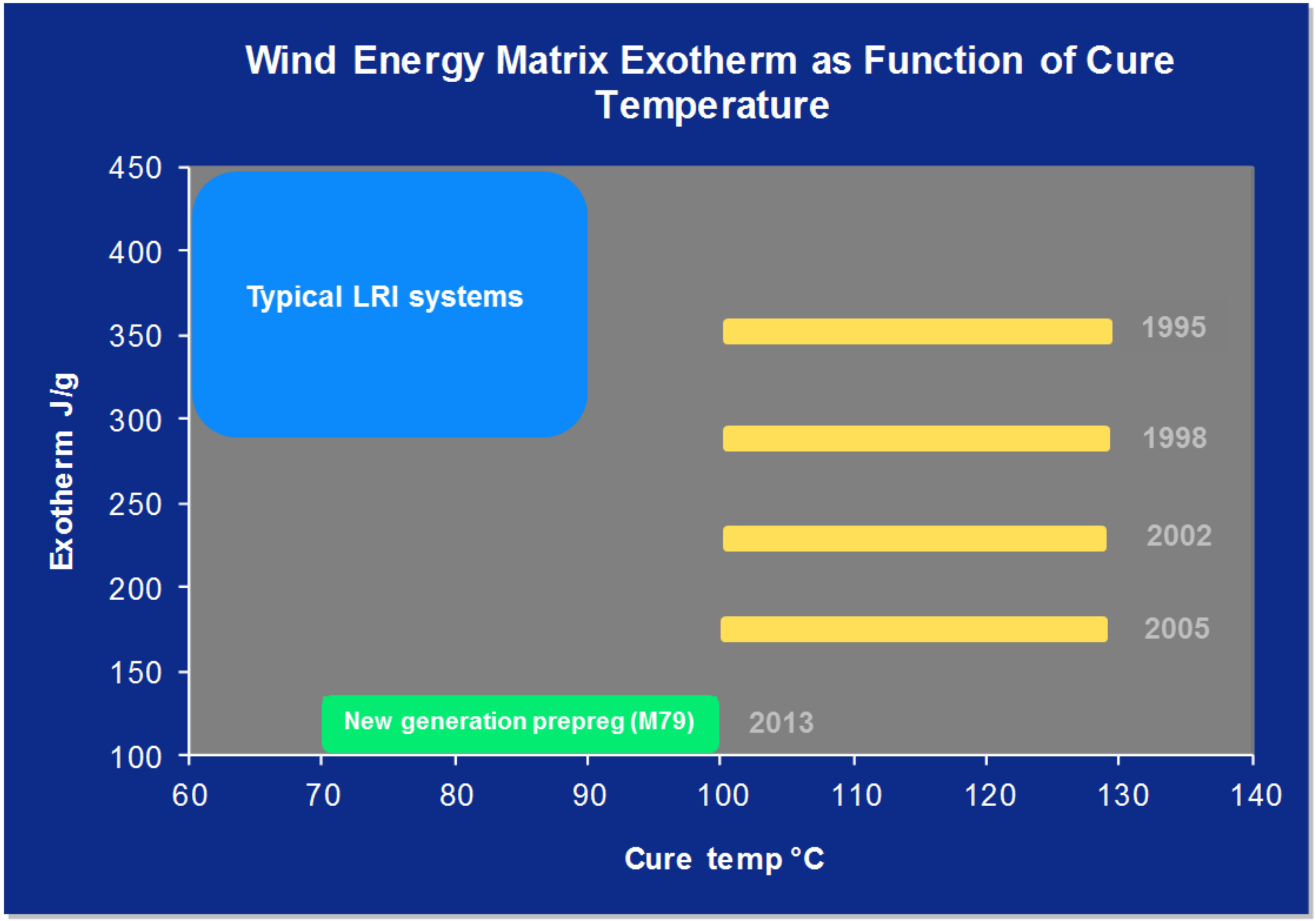
Reduction in Prepreg Exotherm, 1995-2013



Latest matrix helps to minimise reaction exotherm to give short cure cycles for thick structures

HEXCEL

Evolution of Prepreg Systems



Reaction exotherm for infusion systems now about three times prepreg systems with equivalent cure temperatures

HEXCEL

Example of Mechanical Test Data (M79: 70°C cure)

Test & Direction	Measurement	70 ° C Cure				M9 Historical
		No. of specimens	Mean	SD	CV (%)	
Tensile 0°	Strength (MPa)	8	**469**	9.4	2.0	**445**
	Modulus (GPa)		**21.2**	0.5	2.5	**18.2**
Compression 0°	Strength (MPa)	10	**413**	20	4.9	**333**
	Modulus (GPa)		**21.0**	0.3	1.4	**19.5**
ILSS (45° , 4-ply)	Strength (MPa)	20	46.7	1.9	4.0	43.6

Normalized results are in bold

Test results for HexPly M79/43%/LBB1200+CV/G cured at 70 ºC

Overall, mechanical test data compare favourably between new and conventional systems

Summary of Properties

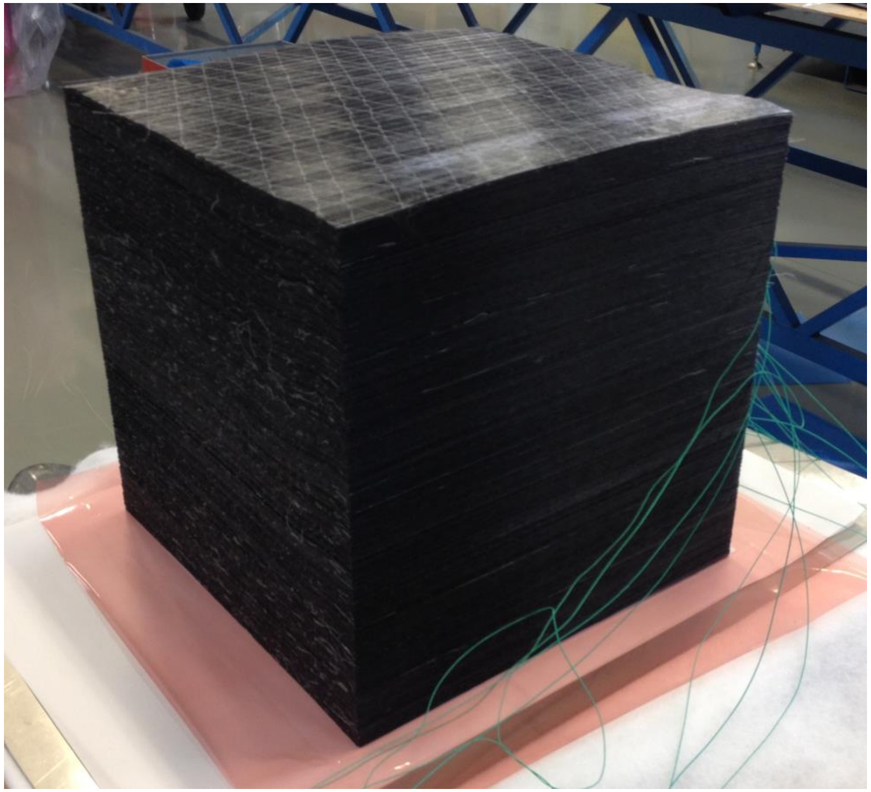
New generation prepreg system for large industrial structures (e.g. wind turbine blades)

Property		Value
Cure time/ temperature	70°C	8-10 hours
	80°C	4-6 hours
Outlife		>2 months
Reaction enthalpy		100-120 J/g
Static mechanical properties		Similar to current products
Product form		Same as current products
Manufacturing process		Same as current products

Performance envelope extended to lower temperatures and even lower exotherm

HEXCEL®

Carbon Cube Demonstrator



Final cube: 40X40X40 cm
~90 kg

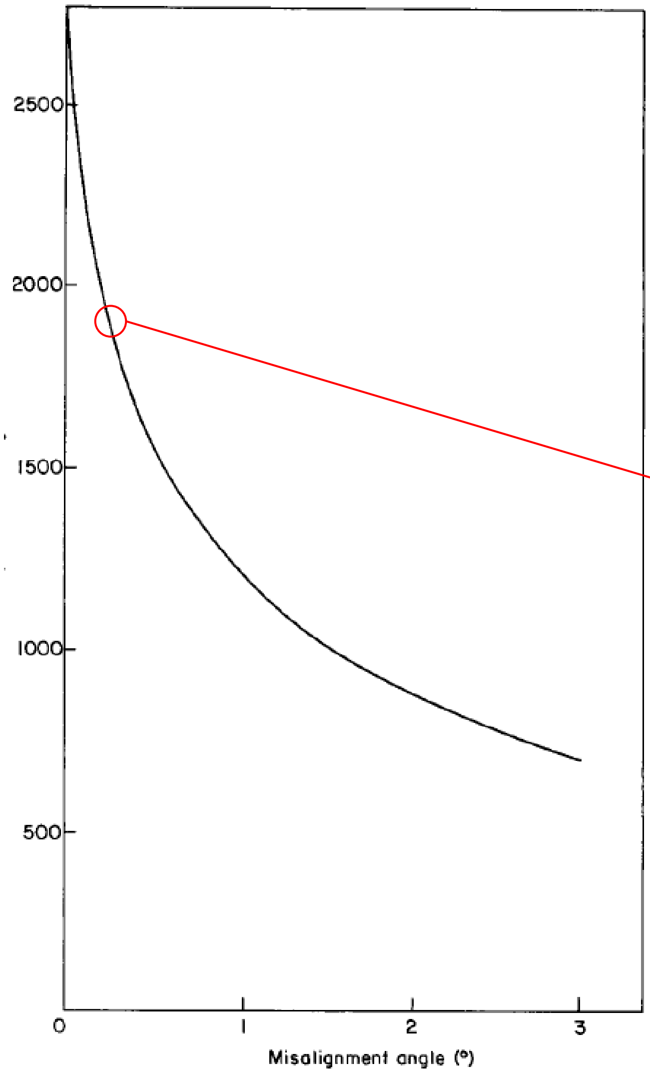
- 695 400X400mm plies of HexPly M79/34%/UD600+2P/CHS+PES
- Standard vacuum bag cured in a press with aluminium mould surround
- Cure temperature 80-100^{o}C, maximum centre temperature of 140^{o}C
- Full cure within 10 hours

Effective demonstration of low exotherm technology

Fibre Alignment

Effect of alignment on mechanical properties

Effect of Fibre Alignment on Compression Strength



The effect of fibre misalignment on the compressive strength of unidirectional carbon fibre/ epoxy

M.R Wisnom: Composites, 21 (1990), 403-407

A deviation of 0.25° (~4mm in 1m) reduces compression strength from 2720 MPa to 1850 MPa

How can fibre alignment be improved?

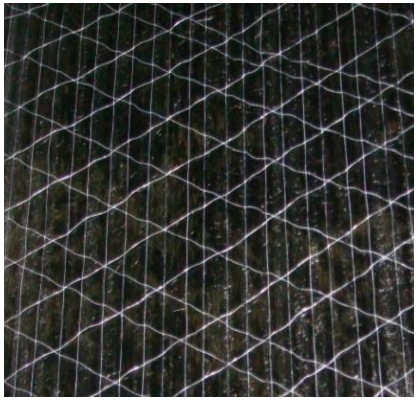
Comparison of Carbon Prepreg vs. Infusion

Infusion

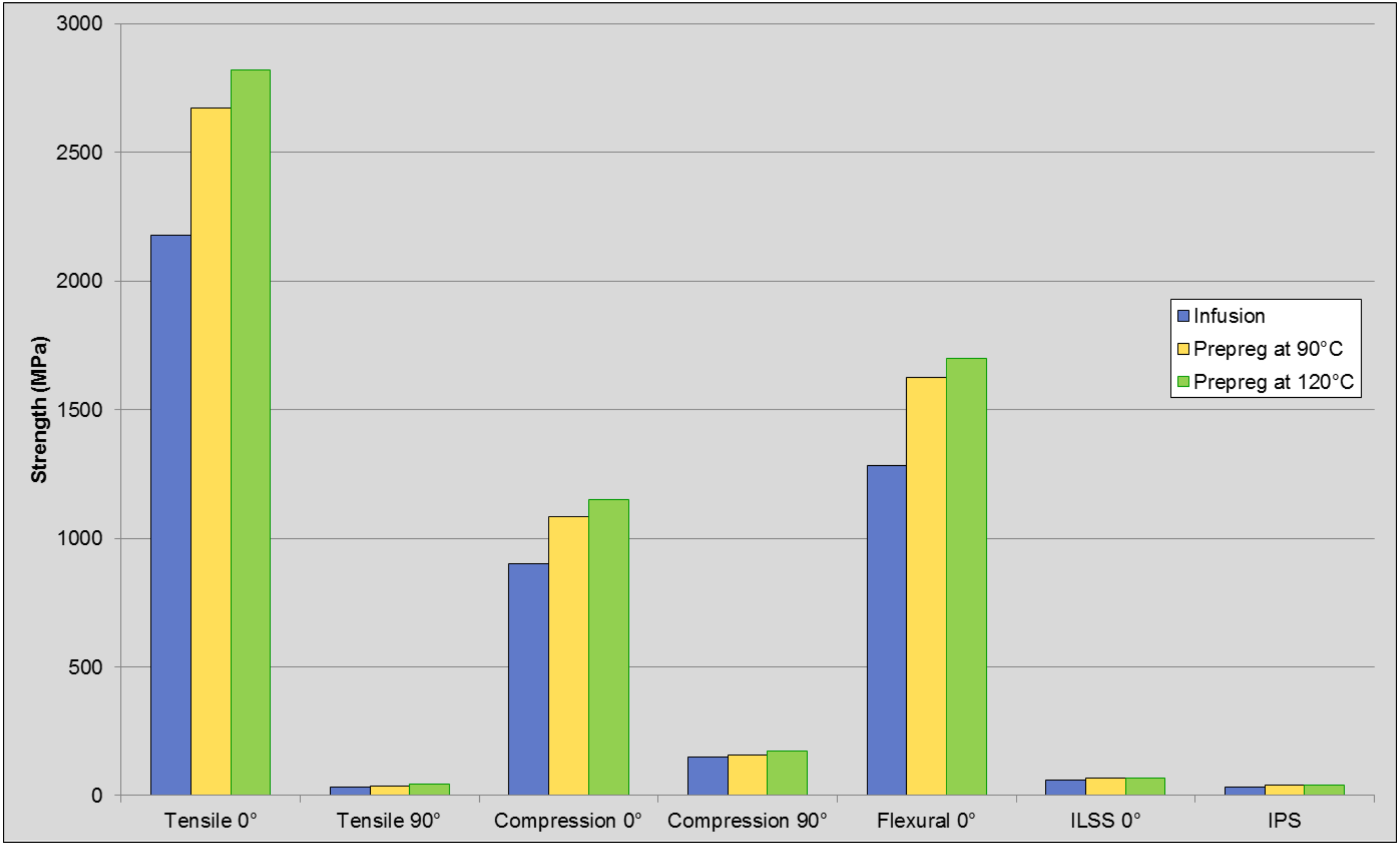
- Reinforcement: UD600 low crimp T620
- Resin: Hexion RIM135
- Cure at 90°C

Prepreg

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



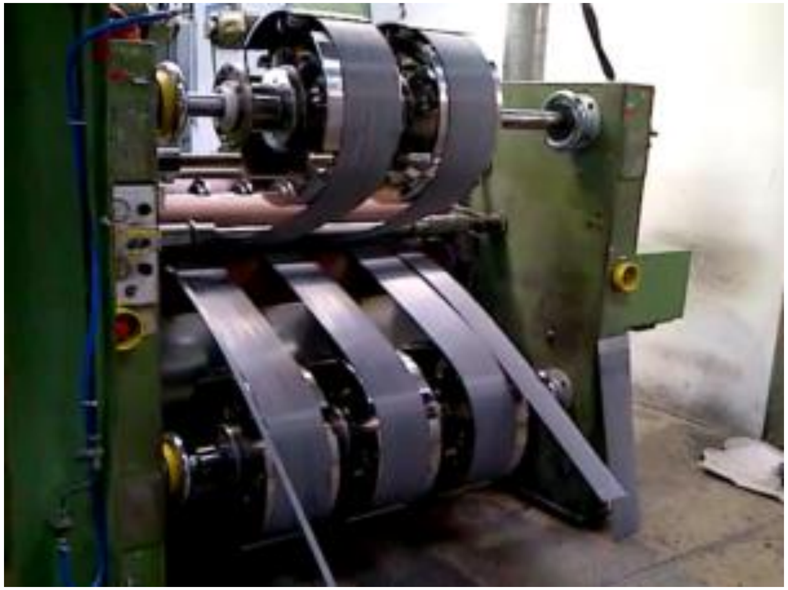
Prepreg vs. Infusion: Mechanical Properties



Prepreg enhances performance

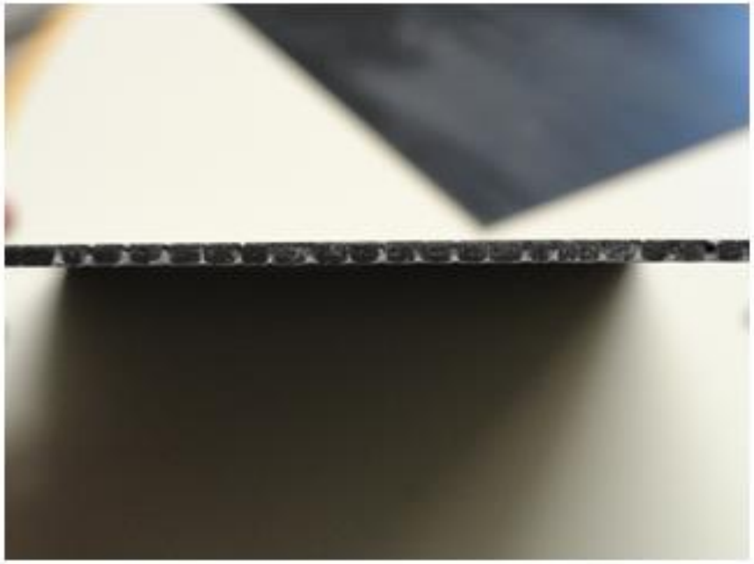
Polyspeed Carbon Laminates

- Belt-pressed, pre-cured carbon laminates for wind and industrial applications
- Fixed fibre alignment: high mechanical properties
- Free of release agent, surface can be tailored
- Can be kitted, chamfered, cut diagonally



Flexible up to 1000mm width, 1800-2000 g/m²

Carbon Laminates



1500 g/m^2 (100% 0^o) C-R150 laminate in plan, section, and assembled into thicker slab

- Fibre alignment is retained
- No subsequent exotherm during final cure

Conclusions

- **The spar cap is heavily driven by performance, and hence drives the potential need for carbon**
- **Using carbon prepreg, porosities<<1% are achieved**
- **Infusion of thick carbon arrays relies on gaps within the fibre array**
- **The trend in prepreg matrix development is to ultra low exotherm (100-120 j/g, M79), enabling shorter cure cycles**
- **Fibre misalignment has a dramatic effect on compression performance**
  - Risk of misalignment is reduced in prepreg, essentially eliminated in laminates

Carbon material forms for wind turbine blades continue to evolve offering a range of high performance options

HEXCEL

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.