HEXCEL®

UD Prepregs for Load Carrying Structures in Infused Blades

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Hexcel Corporation

Agenda

- **Introduction to Hexcel in Wind Energy**
- **Prepreg and infusion technologies**
- **Combinations of prepreg and infusion**
- **Examples**
  - Prepregs in thick laminates
  - Comparison of mechanical properties from prepreg and infusion
  - Case study – large scale trial
- **Conclusions**

Introduction to Hexcel in Wind Energy

Hexcel: Company Profile

- **Leading global provider of advanced composites**
- **Primary markets: aerospace, defence and wind energy**
- **Net Sales of $1.108 billion in 2009**
- **4,000 employees worldwide**
- **Headquarters in Stamford, CT, USA**
- **Listed on NYSE**
- **Manufacturing in nine countries, 18 locations**

Hexcel - Vertically Integrated

Key RM	Technologies	Applications	Products
Acrylonitrile	Carbon Fiber	Carbon Fiber for Prepregs reinforcements for aerospace, wind blades, recreation, and infrastructure	
Aramid Fiber Carbon Fiber Glass Fiber	Reinforcements	Reinforcement for composites (RFC)	
Aluminum Aramid Paper Carbon Fiber Glass Fiber Resins	Composites ▪Prepreg ▪Honeycomb	Prepregs Honeycomb Core Block Resin Systems for wide range of products	
Adhesives Honeycomb Prepregs	Structures	Component assemblies for aerospace HexMC Parts Shaped/Machined Core	

Hexcel in Global Wind Energy

- **Market Leader for prepreg materials in Wind Energy**
- **More than 65000 tons of prepreg products supplied since early 1990s**
- **Global Supply, Sales, Technical Support and R&T**
- **Product development in close cooperation with key accounts**

New plant for wind energy at Windsor Colorado 2009

Infusion and Prepreg Technologies

What are prepregs?
How do prepreg and infusion processes compare?

Impregnation of Fibre and Fabrics from Resin

Prepreg production is now highly industrialised for optimum cost and quality

Typical Prepreg Systems in Wind Energy

- **Resin systems**

M9	**290 J/g**
M9F	**250 J/g**
M19	**190 J/g**

- **Product forms (UD)**

  Carbon 500-600 gsm

  Glass 1000-3000 gsm

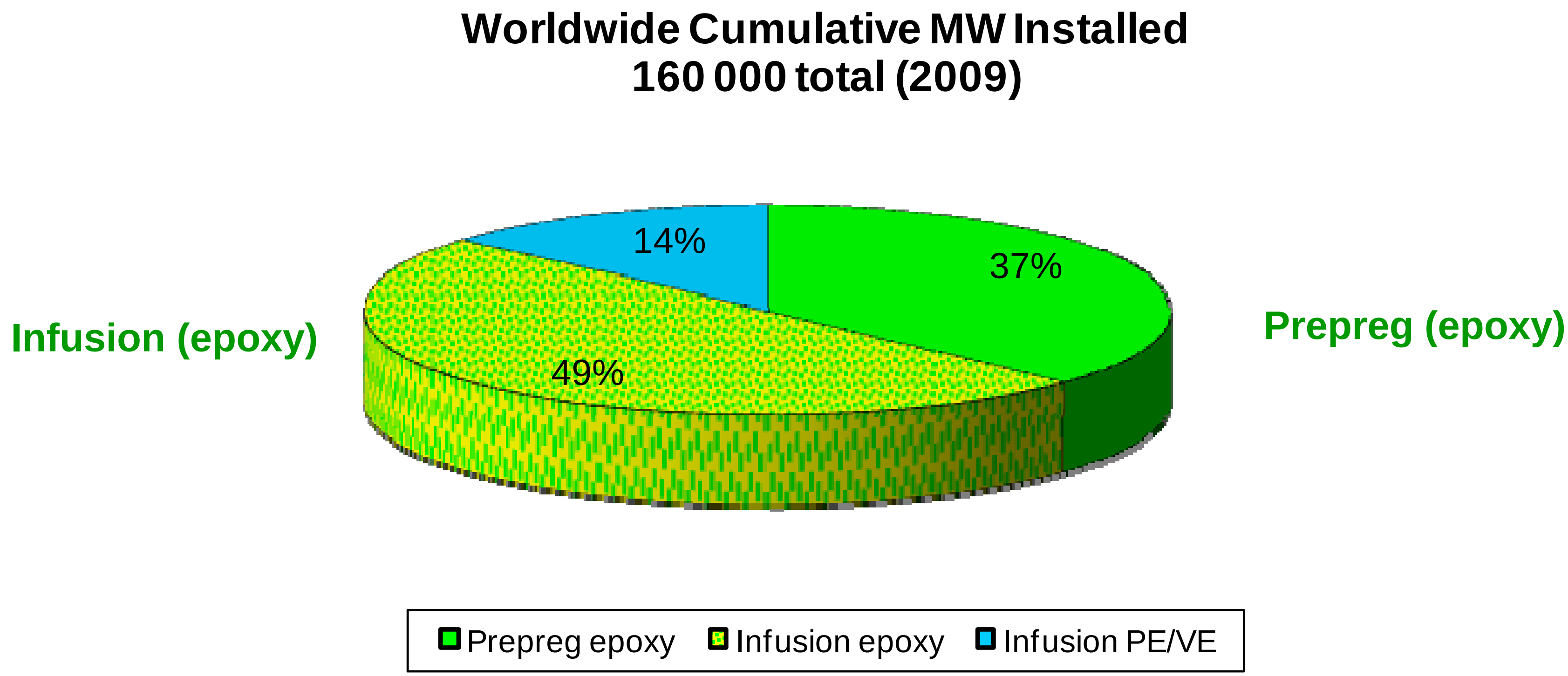
- **Cure cycles (ramps, dwells + cure times)**

  ~4 (M19) to ~8 (M9) hours when optimised

- **Storage at +5^{o}C (6 month shelf life)**

Typical prepregs combine high areal weights, full impregnation, and low reaction enthalpies

Prepreg and Infusion in Wind Energy



The split between prepreg and infusion for blade manufacture is similar

Blade technology: Infusion versus Prepreg

	Infusion	Prepreg
Raw Material Cost €/kg €/m³	~ 3.0 (resin + glass NCF) Foam: 1600 +	UD: 2.8 to 3.3/ Glass NCF ~ 4.0 Foam: 1800 -
Tooling Cost	++	- -
Capex Requirements	+	-
Layup	-	+
Cure Cycle	- Up to 20 hours	+ Up to 10 hours
Blade Finishing	+	-
Health & Safety	-	+
Waste & Scrap	- -	-
Throughput & Quality Control	- -	++
Mechanical Performance	-	+

Both technologies have their pros and cons

Why not combine Prepreg and Infusion Technologies?

Combinations of Prepreg and Infusion Technologies

Proposal

Use prepreg in load critical structures (spar caps or girders)

Benefits

Full impregnation (even in thickest structures, even with carbon)

Choice of chemistry (reaction enthalpy) to suit cycle

Low exotherm

Benefits (to be demonstrated)

Low porosity in laminate

Fast cure cycle

Maximum mechanical properties from pure UD

Combinations of Prepreg and Infusion Technologies

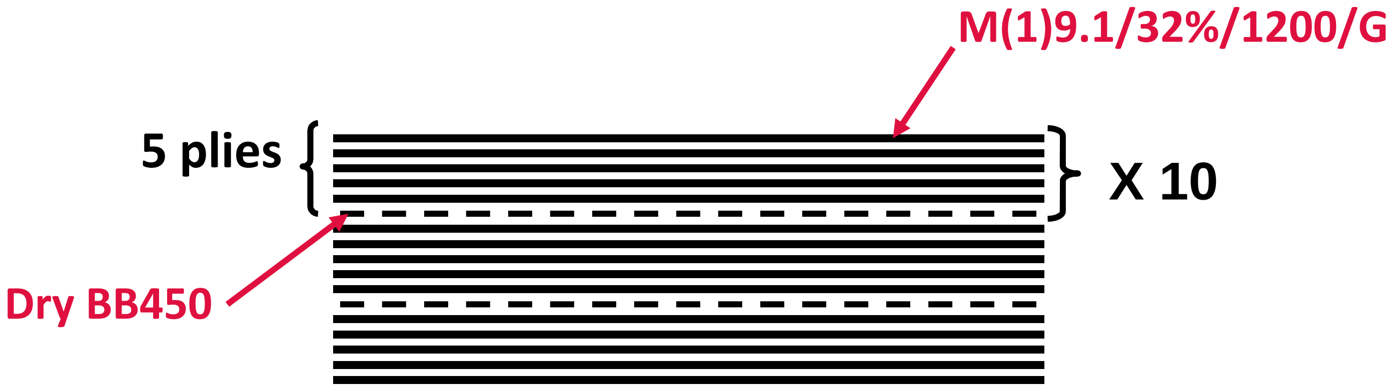
Three examples

1. Prepregs in thick laminates
2. Comparison of mechanical properties from prepreg and infusion
3. Case Study: Large scale trial of prepreg in a spar cap

Prepregs in Thick Laminates

Example 1

Cure Cycles Using Low Exotherm Prepregs



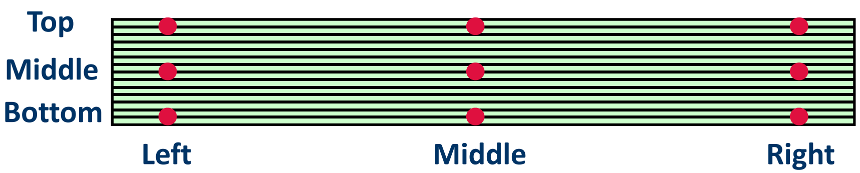
60 prepreg plies

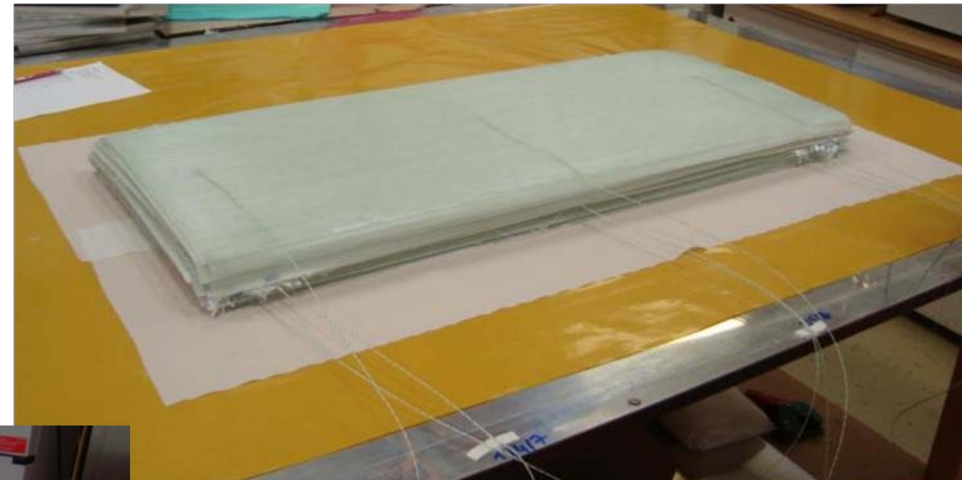
11 biax layers

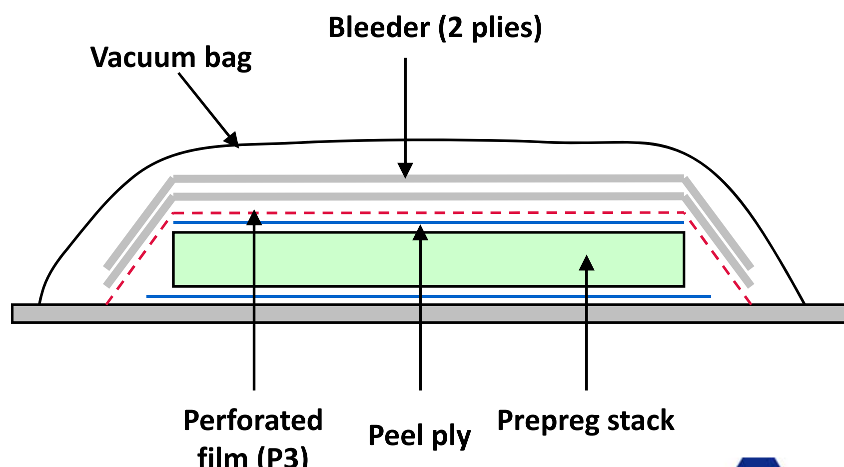
～ 6 cm thick

Cure Cycles: Layup Configuration

Thermocouples



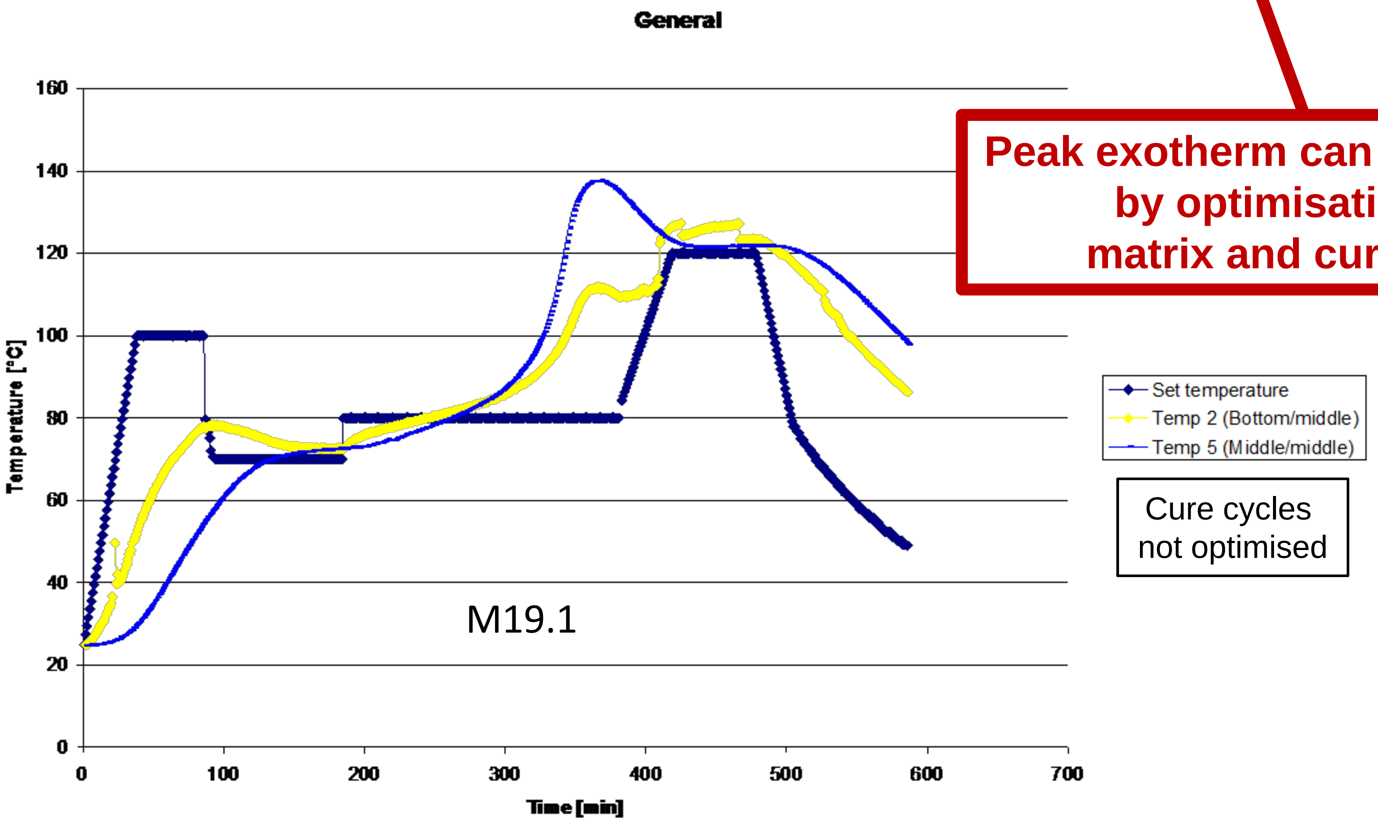




Cure Cycles: Results

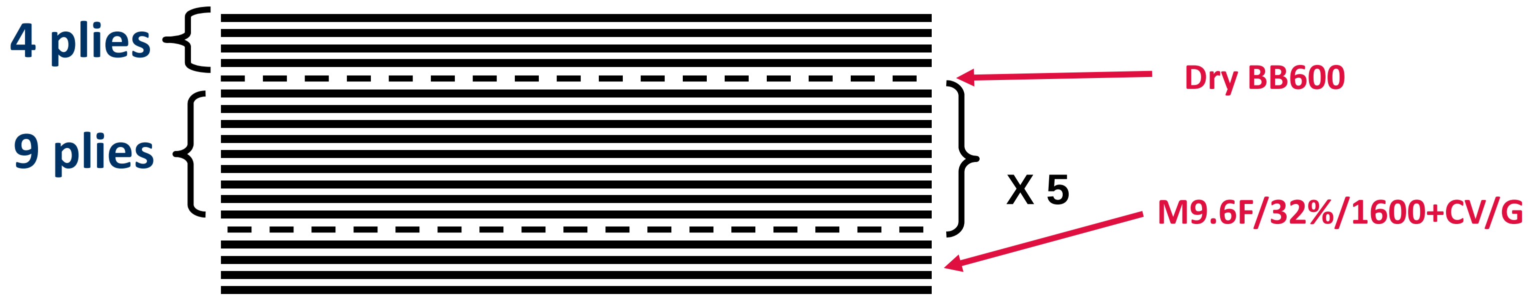
		M9.1	M19.1
Maximum temperature (°C)	*Tool surface*	125	112
	In the middle	166	138
Exotherm after (hours)		4	6

Peak exotherm can be reduced by optimisation of matrix and cure cycle



Cure cycles not optimised

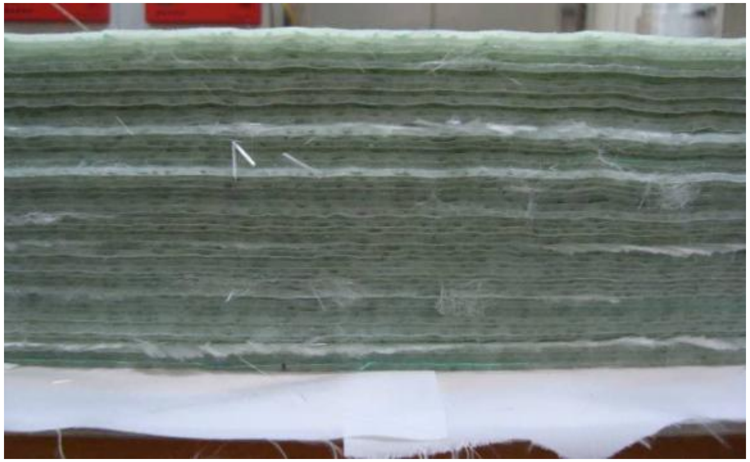
Low Porosity in Thick Laminates



53 prepreg plies

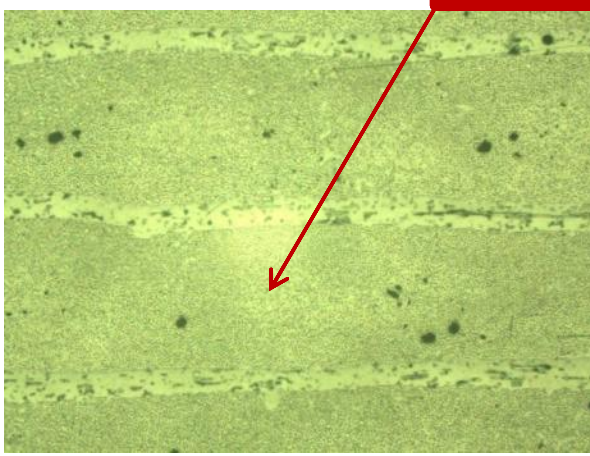
6 biax layers

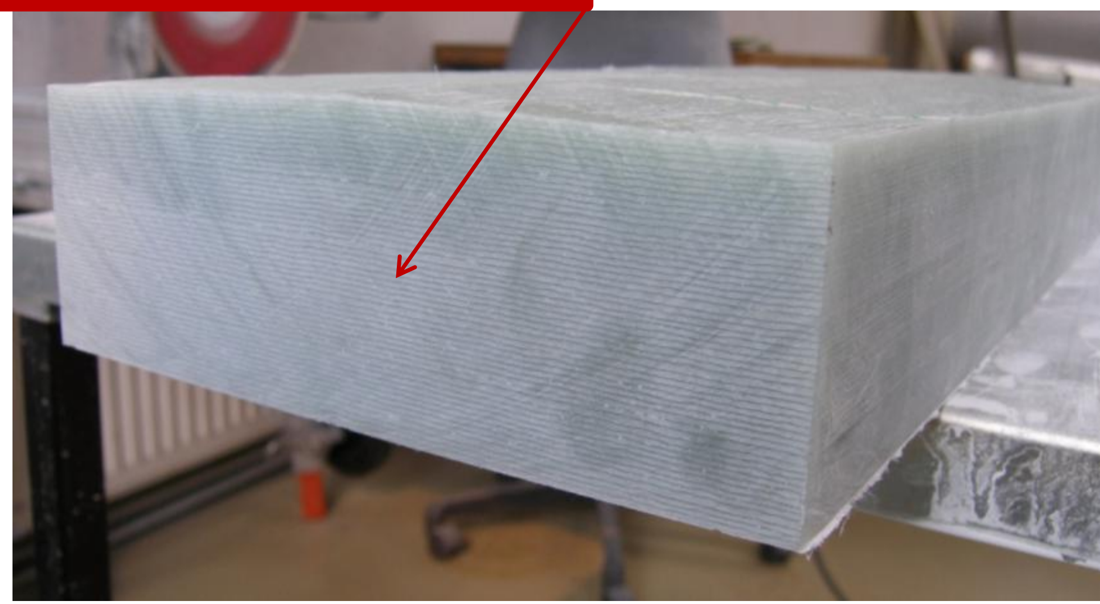
～ 6 cm thick



Low Porosity: Results

Very low porosities can be achieved with standard prepregs even in thick laminates





Fiber volume (%)	Air content (%)
51,9	0,2

Comparison of Mechanical Properties from Prepreg and Infusion

Example 2

Mechanical Evaluation - Overview

Prepreg panel cured at 100°C

Mechanical comparison

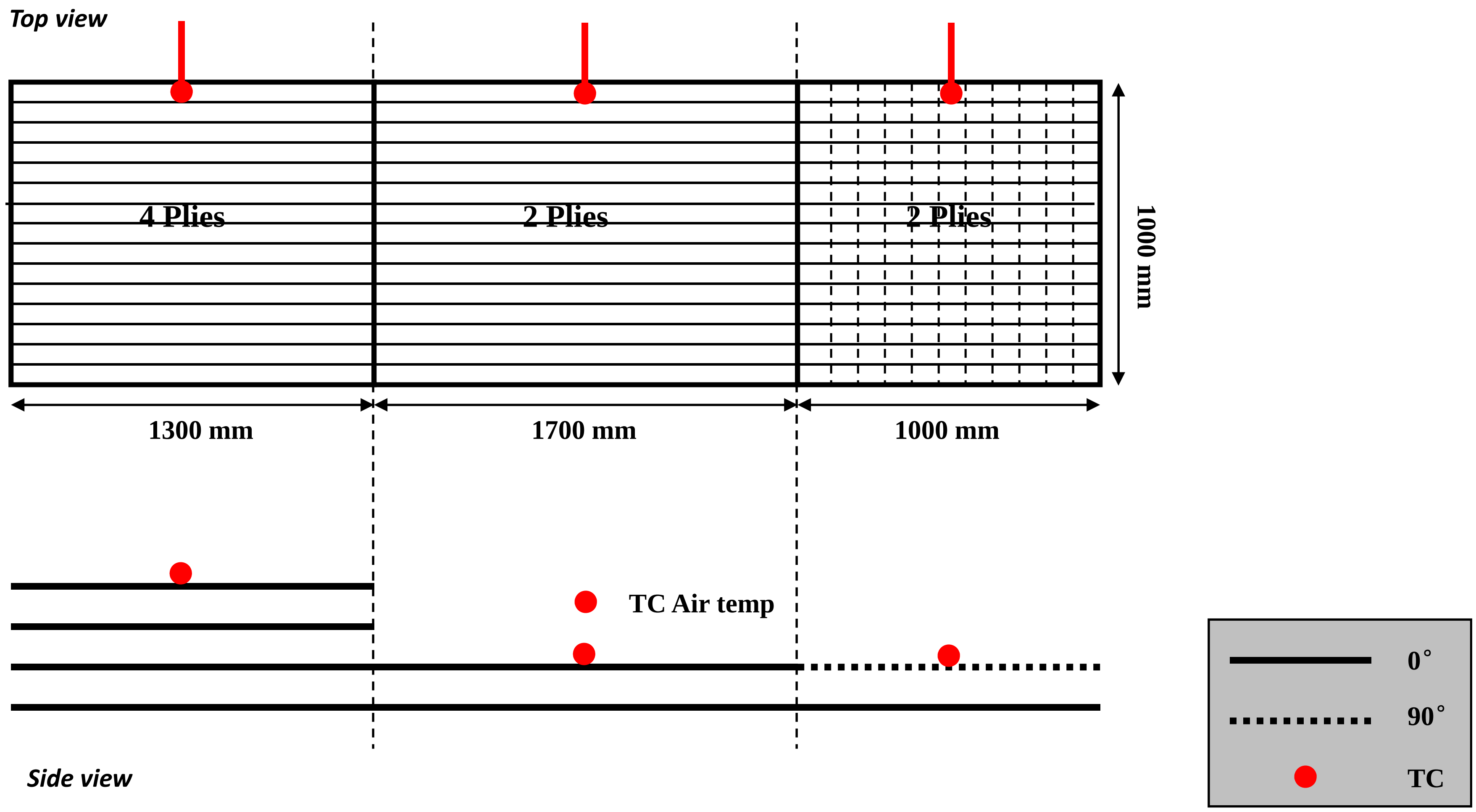
Infusion panel cured at 100°C

Reference prepreg panel cured at 120°C under pressure

(gives ultimate performance)

Test	Plies
Tensile 0°	2
Tensile 90°	2
	4
Compression 0°	2
ILSS/ SBS	4
IPS	2

Mechanical Evaluation - Trial Layup

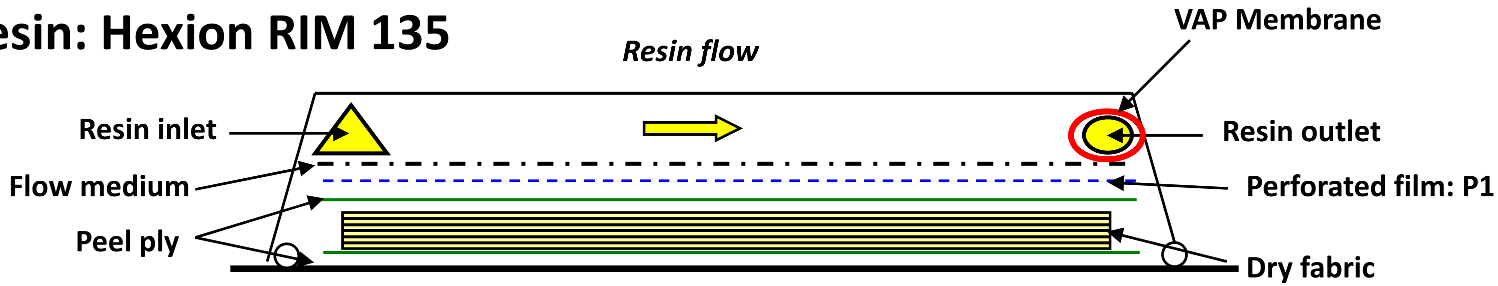


Mechanical Evaluation - Trials

Infusion:

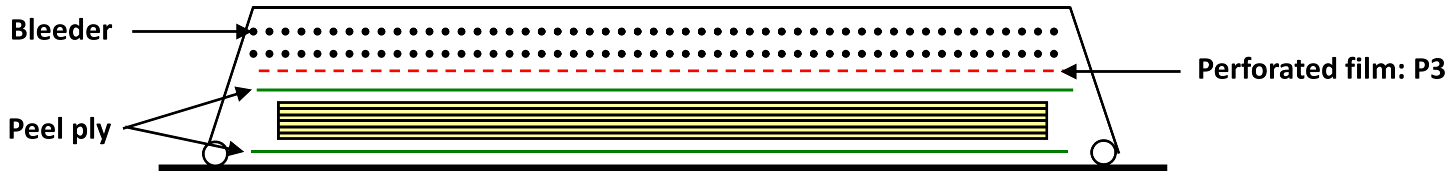
→ **Reinforcement: LT1218 (stitched UD)**

→ **Resin: Hexion RIM 135**



Prepreg:

→ **M9.1/32%/1200/G**

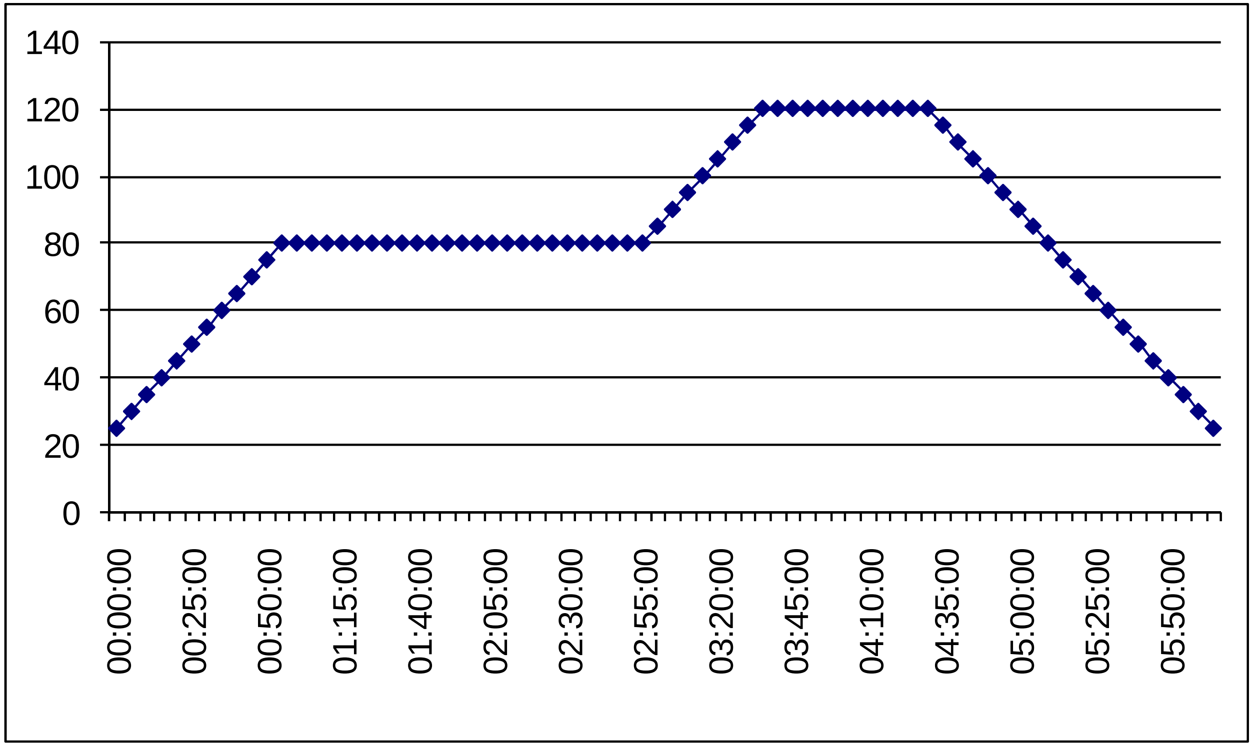


Prepreg and infusion panels given the same cure of 6 hours at 100ºC

Mechanical Evaluation – Reference

- → **M9.1/32%/1200/G**
- → **8 bars**
- → **Cure cycle:**

Defines ultimate performance of prepreg



Mechanical Evaluation: Results

Panel Characterisation:

	Reference	Prepreg	Infusion
Fiber volume (%)	70,1	65,3	58,9
Air volume (%)	0	1.55	1.45
Tg (DSC) (°C)	127,1	124,8	74,2

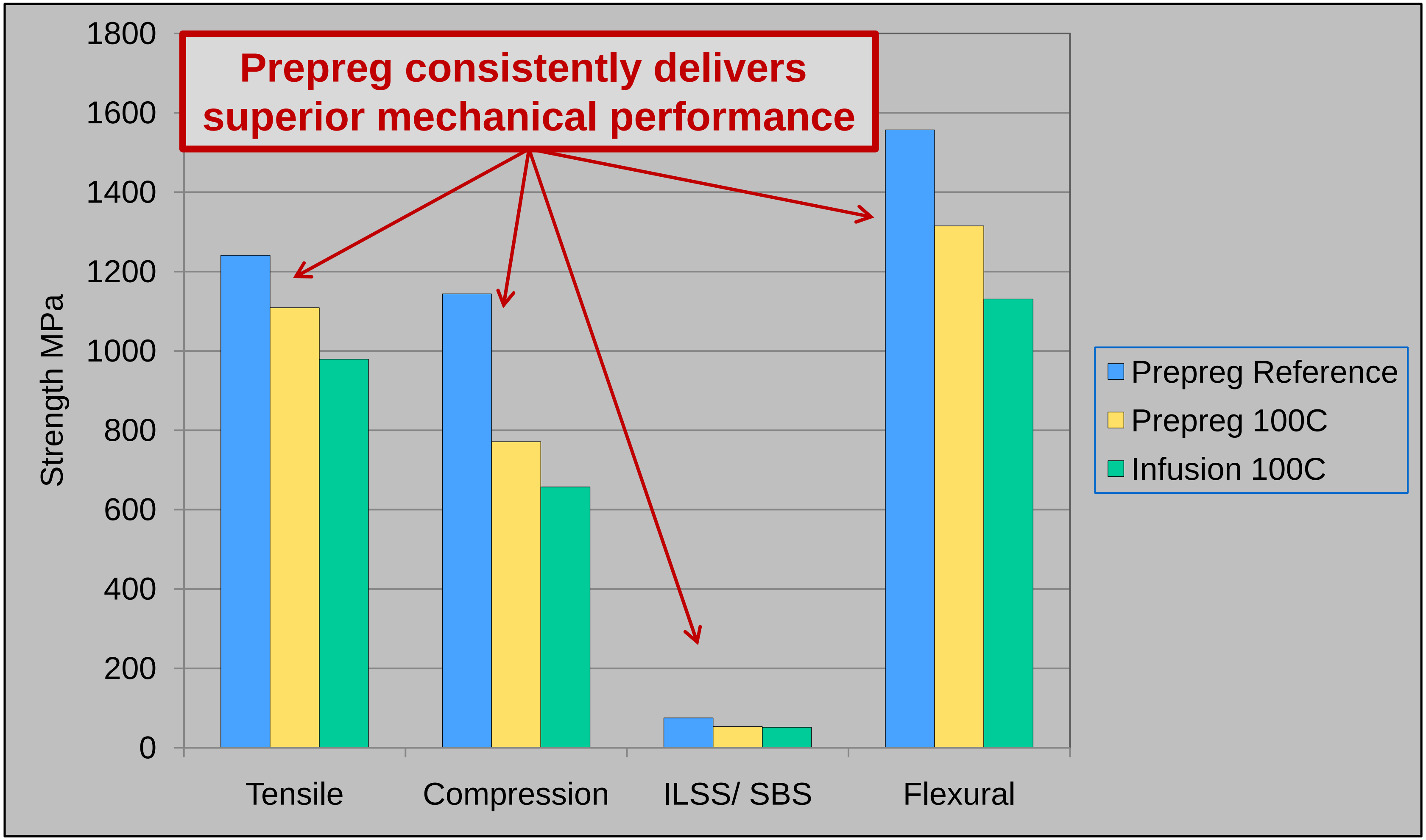
Mechanical results:

Test	Standard test method	Plies	Prepreg reference		Prepreg		Infusion	
			Strength (MPa)	Modulus (GPa)	Strength (MPa)	Modulus (GPa)	Strength (MPa)	Modulus (GPa)
Tensile 0° *	EN ISO 527	2	1241	48.7	1109	47.7	979	46
Tensile 90°		2	48	16.9	28.93	14.29	47.75	12.61
Compression 0° *	ISO 14126	2	1144	51.8	771.3	45.35	657.3	49.73
ILSS/ SBS	ISO 14130	4	75.3		53.4		51.7	
Flexural 0° *	ISO 14125	4	1557	42.7	1315	37.7	1131	33.2
IPS	EN 6031	2	45.1	6.4	36.5	4.8	43.2	3.5

* normalised to FV=60%

100MPa= 14.5ksi

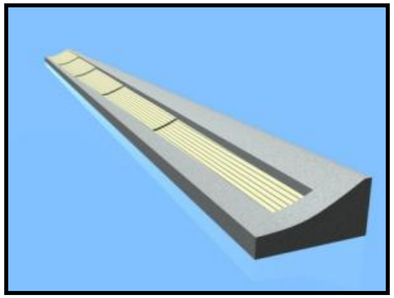
Mechanical Evaluation: Results

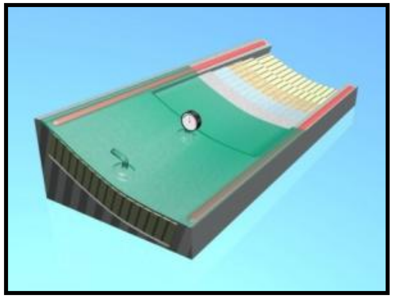


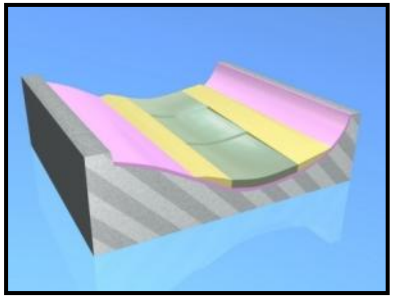
Case Study
Large Scale Trial of Prepreg in a Spar Cap

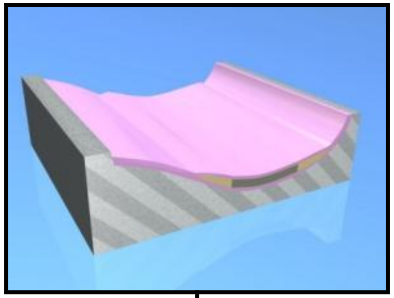
Example 3

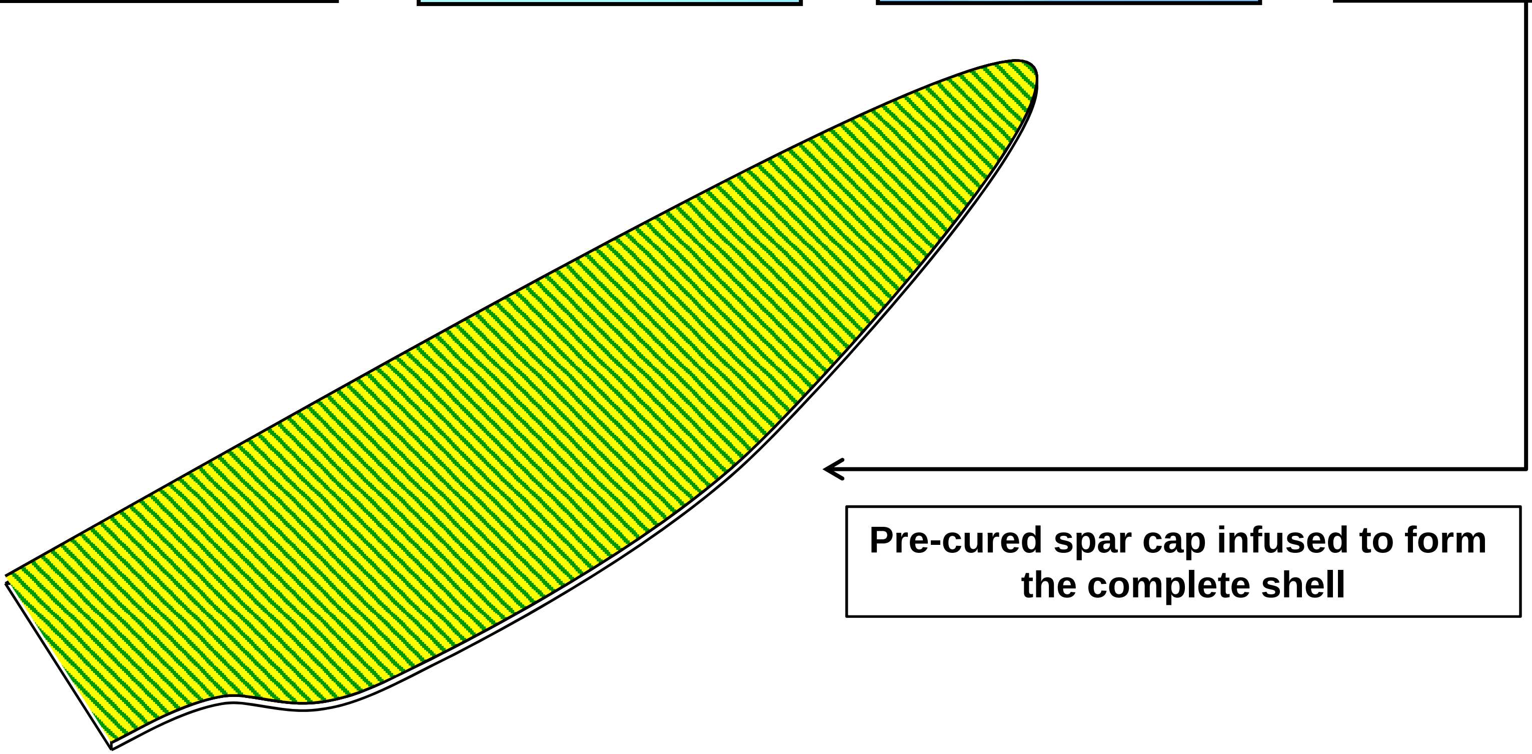
Use of Prepreg for Spar Cap Construction











Pre-cured spar cap infused to form the complete shell

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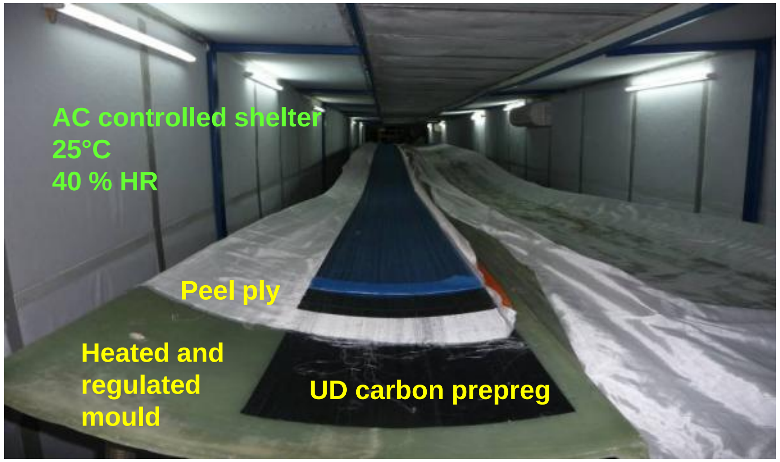
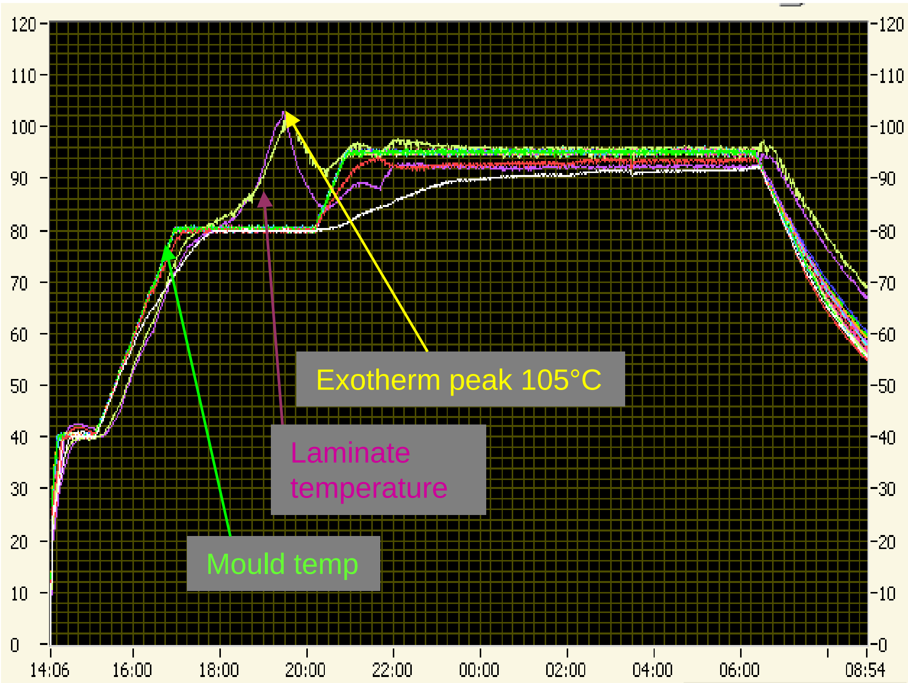
Case Study: Carbon Girder at Half Scale

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

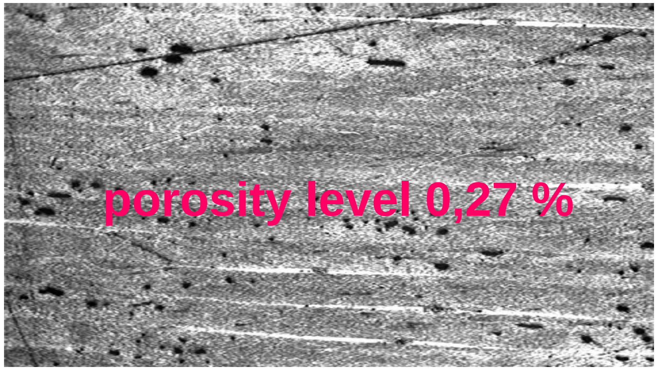




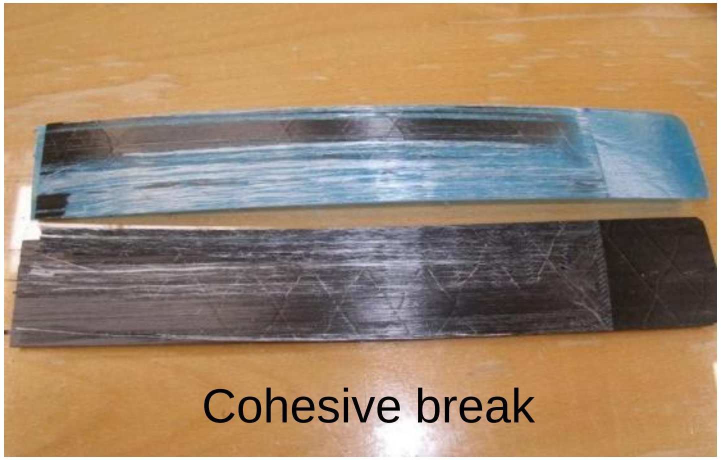
UD prepregs are ideally suited to automated layup

Case Study: Results

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



Typical cross section of cured laminate



Good adhesion of infused glass on prepreg carbon laminate

Conclusions

- **Typical prepregs in wind energy combine high areal weights, full impregnation and low enthalpy**
- **These result in the following:**
  - Fast lay down of heavy weight structures, ideally suited to automation
  - Reliable low porosity, even in thick laminates
  - Short cure cycles
- **The same is true of both carbon and glass**
- **Typical UD prepregs can have significantly higher mechanical properties than their infused equivalents**

The use of UD prepregs in load bearing structures enhances mechanical properties, reliability and productivity