A presentation by Dr Chris Shennan

25 May 2011

# Use of Prepregs to Improve Spar Caps in Infused Blades

# *Hexcel – Company Profile*

- **Leading global provider of advanced composites**
- **Technology leader with largest portfolio of qualifications**
- **Primary markets: commercial aerospace, space & defense, wind energy and industrial**
- **Net Sales of $1,174 million in 2010**
- **4,000 employees worldwide**
- **18 production sites (including JV in Malaysia)**
- **Headquarters in Stamford, CT, USA**
- **Listed on NYSE**

**Windsor, Co site opened in 2009 for production of wind energy materials**

HEXCEL

# Prepreg Technology and Infusion

**What are prepregs?**
**Why use prepregs, and where?**

# *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** | **280 J/g** |
| **M9GF** | **230 J/g** |
| **M19G** | **150 J/g** |

- **Product forms (UD)**

  **Carbon 500-600 gsm**

  **Glass 1000-3000 gsm**

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

  **~4 (M19G) to ~8 (M9G) hours when optimised**

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

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

HEXCEL

# *Blade technology: Infusion versus Prepreg*

| | Infusion | Prepreg |
|---|---|---|
| **Raw Material Cost** $/lb<br>$/m$^3$ | ~ 1.8 (resin + glass NCF)<br>Foam: 2200<br>+ | UD: 1.8 to 2.0/ Glass NCF ~ 2.5<br>Foam: 2500<br>- |
| **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**

HEXCEL

# *Major Features of Prepregs in Wind Energy*

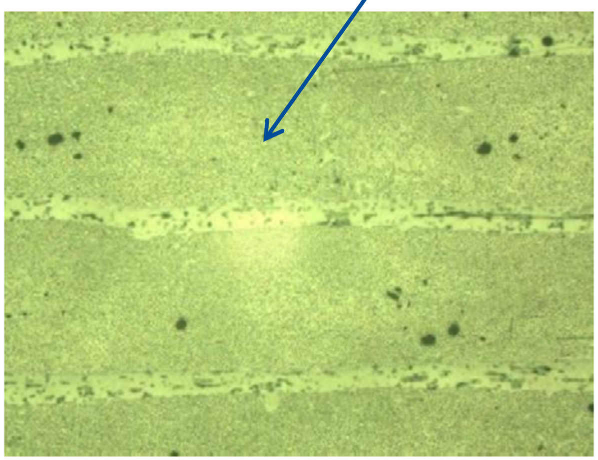
- Chemistry choice to suit cure cycle/part
- Full impregnation: carbon, glass
- Low controllable exotherm
- Choice of architecture for lowest porosity
- Maximum mechanical properties
- Lowest cost in UD formats

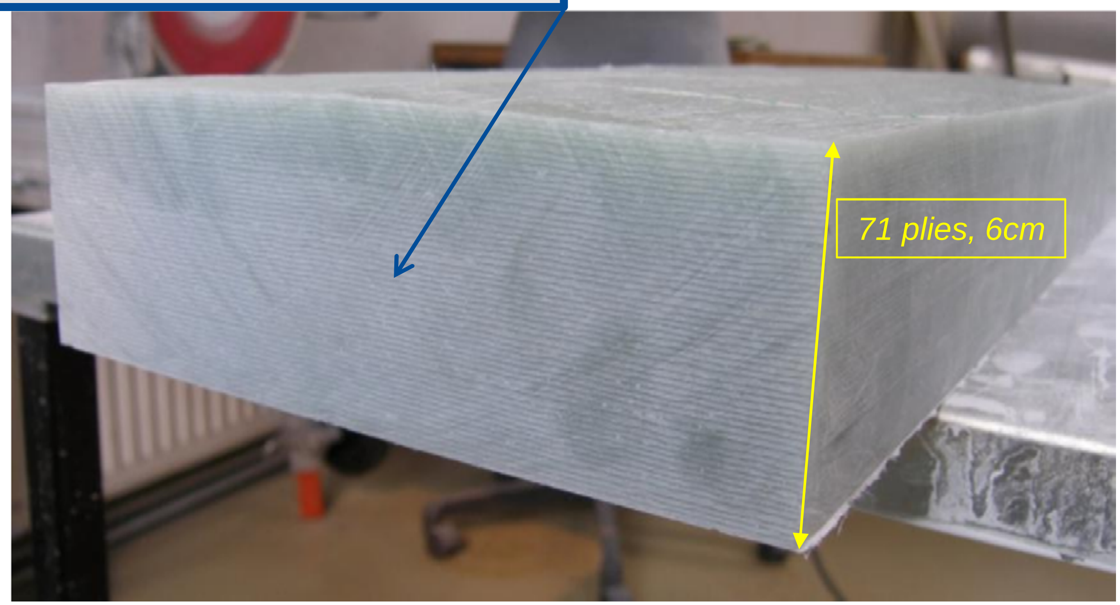
**Prepregs are ideally suited for thick load critical structures in spar caps**

# Porosity in Thick Laminates

# *Prepregs in Thick Glass Laminates*

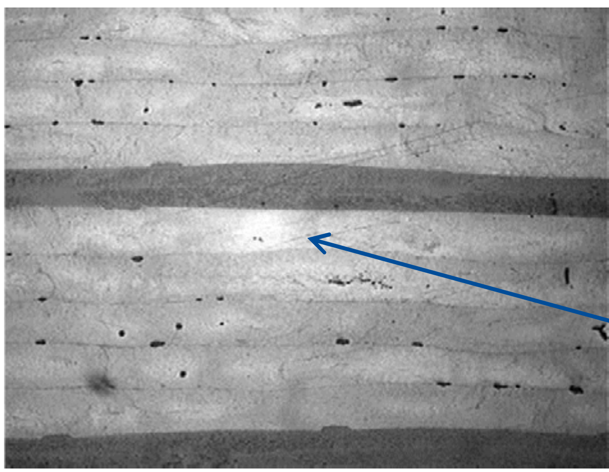
Very low porosities from standard prepregs even in thick laminates





# *Prepregs in Thick Carbon Laminates*

Typical results in thick laminates using
600gsm carbon (HS) prepreg and <u>standard</u> technology
Porosity ~7%



Improvements in thick laminates using
Hexcel patented technology
Porosity <<1%

**Very low porosities even in thick laminates: Selection of the right prepreg architecture is key**

# Mechanical Properties Using Prepreg and Infusion

## Glass

# *Glass: Materials*

***Infusion:***

**Reinforcement:** **LT1218 (UD1200 + slight reinforcement in 90°)**

**Resin: Hexion RIM 135**

**Cure at 90°C**

***Prepreg:***

**M9.6GLT/32%/1200(+CV)/G**

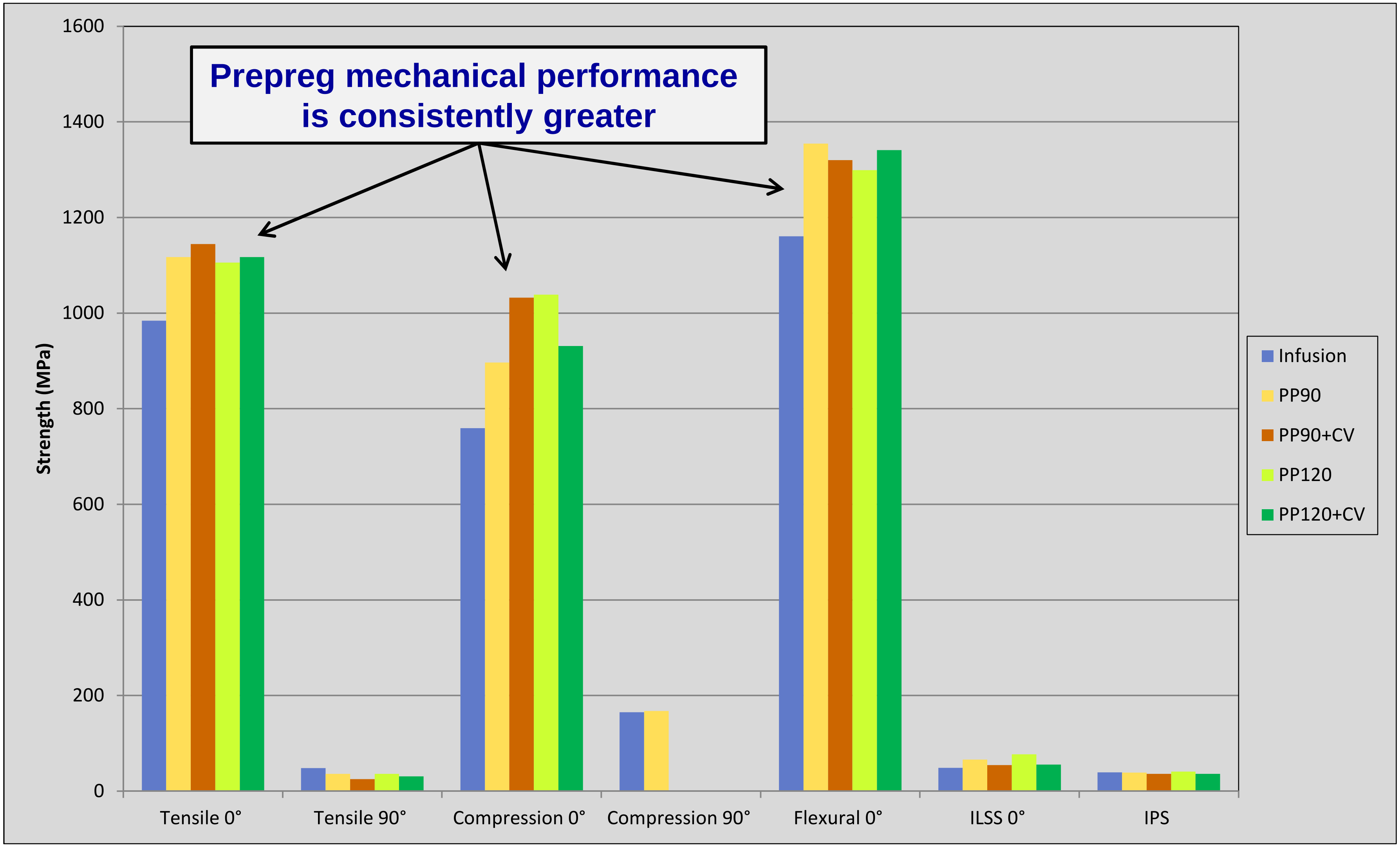
**Cure at 90°C (‘PP90’) and 120°C (‘PP120’)**

# *Glass: Mechanical Properties*

| Property | | Norm | Infusion | PP90 | PP90+CV | PP120 | PP120+CV |
|---|---|---|---|---|---|---|---|
| Tensile 0° * | Strength (MPa) | ISO527 | 984.3 | 1117.3 | 1144.2 | 1105.5 | 1117.1 |
| | Modulus (GPa) | | 46.4 | 47.4 | 45.6 | 47.7 | 45.8 |
| Tensile 90° * | Strength (MPa) | | 48.3 | 36.0 | 25.3 | 36.3 | 31.2 |
| | Modulus (GPa) | | 9.66 | 12.7 | 8.87 | 10.7 | 12.2 |
| Compression 0° * | Strength (MPa) | EN2850B | 759.5 | 896.7 | 1032.6 | 1038.6 | 931.3 |
| | Modulus (GPa) | | 47.1 | 48.7 | 49.0 | 49.0 | 48.3 |
| Compression 90° | Strength (MPa) | | 165.4 | 168.0 | | | |
| | Modulus (GPa) | | 13.9 | 15.9 | | | |
| Flexural 0° * | Strength (MPa) | ISO14125 | 1160.5 | 1354.5 | 1320 | 1299 | 1341 |
| | Modulus (GPa) | | 30.7 | 36.4 | 32.5 | 32.9 | 31 |
| ILSS 0° | Strength (MPa) | ISO14130 | 48.7 | 66.2 | 54.7 | 77.3 | 55.8 |
| IPS | Strength (MPa) | ISO14129 | 39.2 | 38.9 | 36.5 | 40.9 | 36.3 |
| | Modulus (GPa) | | 3.40 | 4.50 | 4.2 | 3.9 | 4.2 |

*** Normalised at FV=60%**

# Glass: Mechanical Properties



# Mechanical Properties Using Prepreg and Infusion

## Carbon

# *Carbon: Materials*

***Infusion:***

**Reinforcement: UD600 low crimp T620**

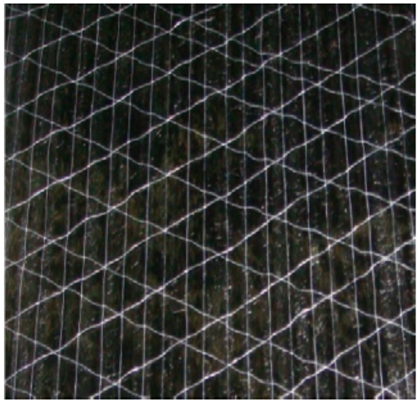
**Resin: Hexion RIM 135**

**Cure at 90°C**

***Prepreg:***

**M9.6GLT/35%/UD600+8P/T620+PES**

**Cure at 90°C and 120°C**

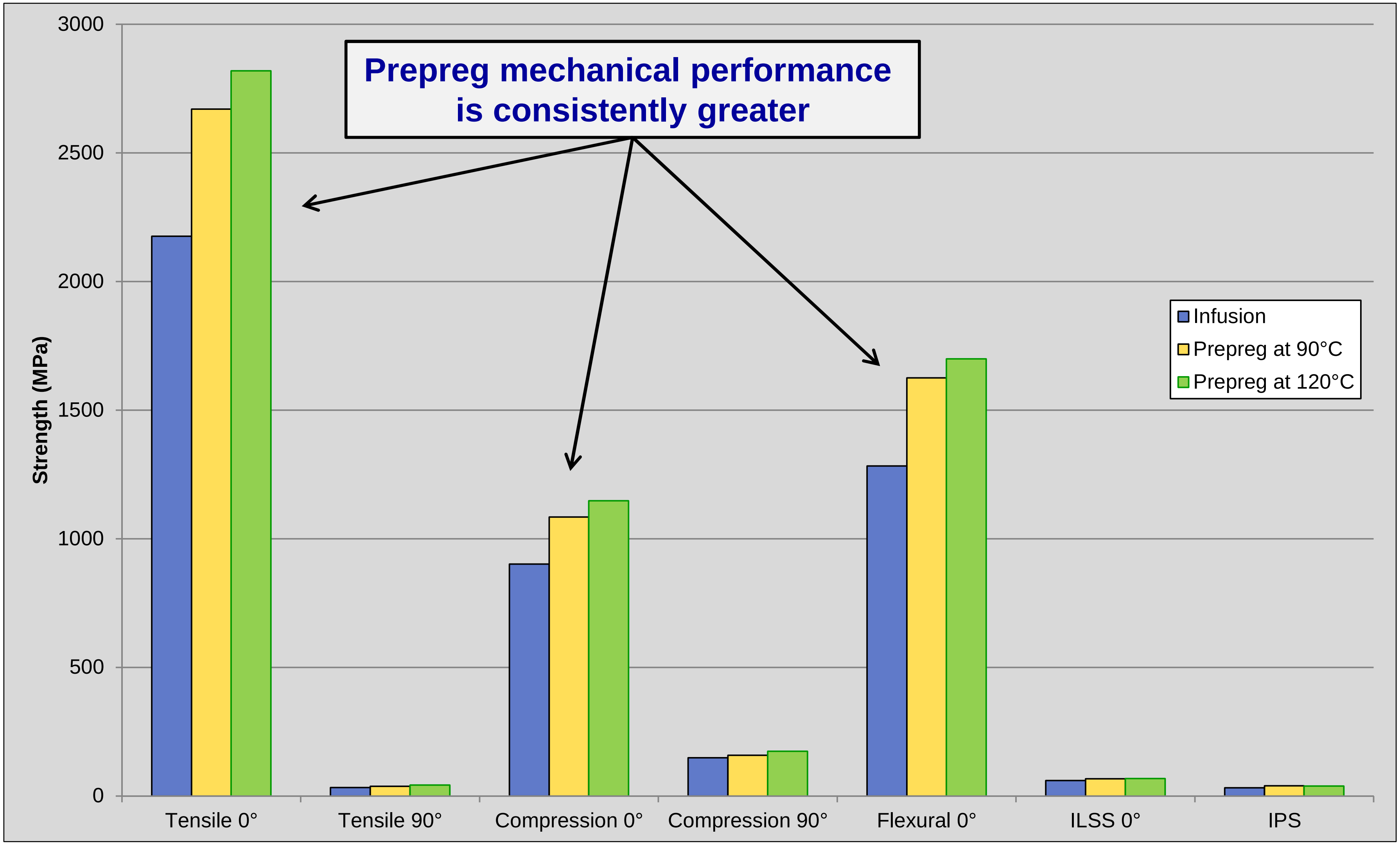


# *Carbon: Mechanical Properties*

| Property | | Norm | Infusion | PP90 | PP120 |
|---|---|---|---|---|---|
| **Tensile 0° *** | Strength (MPa) | ISO527 | 2176,1 | 2670,2 | 2819,8 |
| | Modulus (GPa) | | 130 | 125 | 128,4 |
| **Tensile 90°** | Strength (MPa) | | 33 | 37,9 | 42,9 |
| | Modulus (GPa) | | 8,4 | 8,2 | 7 |
| **Compression 0° *** | Strength (MPa) | EN2850B | 902 | 1085 | 1148 |
| | Modulus (GPa) | | 128,5 | 125.1 | 119.8 |
| **Compression 90°** | Strength (MPa) | | 148,6 | 158,3 | 173,6 |
| | Modulus (GPa) | | 9 | 9,2 | 9,3 |
| **Flexural 0° *** | Strength (MPa) | ISO14125 | 1283 | 1626 | 1700 |
| | Modulus (GPa) | | 103,1 | 103,6 | 114,6 |
| **ILSS 0°** | Strength (MPa) | ISO14130 | 60,6 | 66,7 | 67,6 |
| **IPS** | Strength (MPa) | ISO14129 | 32,2 | 39,6 | 39,2 |
| | Modulus (GPa) | | 4,2 | 4 | 3,9 |

*** Normalised at FV=60%**

# Carbon: Mechanical Properties



# Benefits in Blade Design from Using Prepregs

## *Blade Design Study*

**A study was commissioned at aerodyn to replace an infused Spar Cap in an all glass blade with one based on prepreg**

- To evaluate potential weight/ material savings
- Process pros/ cons were excluded
- Potential benefits for turbine loads excluded

**Blade selected**

- aerodynBlade ae2.5-50.3 IECIII (usually made from resin-infused glass fiber)

**Basis for the study**

- aerodyn data for infused laminates
- Hexcel data (from IMA Dresden) for prepreg laminates (M9.6F/ 32%/1600+50/G+F, 2400 tex E-glass)
- Optimisation of the blade design

HEXCEL

## *Blade Design Study*

**Key conclusions (when an infused glass spar cap is replaced with a prepreg design)**

13% weight reduction in the Spar Cap

33% saving in number of UD layers in Spar Cap mould

3.7% weight saving in the overall blade

(Equivalent to $1200 material cost saving and $750 process cost saving)

**Design Study to be extended to carbon**

## *Conclusions*

- **Prepregs can be tailored to suit wind blade manufacture**
  - Matrix choice minimises exotherm in thick parts
  - Fast cure and low exotherm minimise cure cycle
  - Well-designed prepreg architecture minimises porosity
  - Reinforcements are reliably and fully impregnated, even with carbon and even in the thickest sections
- **Mechanical properties of typical UD prepregs are significantly higher than infused equivalents**
- **These properties translate into benefits in blade design that lead to savings of materials, weight and cost**

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