Improved Materials and Processes for Wind Turbine Blades

by Chris Shennan

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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

<table>
<thead>
<tr>
<th>Key RM</th>
<th>Technologies</th>
<th>Applications</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acrylonitrile</td>
<td>Carbon Fiber</td>
<td>Carbon Fiber for Prepregs reinforcements for aerospace, wind blades, recreation, and infrastructure</td>
<td><img src="image1.png" alt="Image" /></td>
</tr>
<tr>
<td>Aramid Fiber</td>
<td>Reinforcements</td>
<td>Reinforcement for composites (RFC)</td>
<td><img src="image2.png" alt="Image" /></td>
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<tr>
<td>Carbon Fiber</td>
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<tr>
<td>Glass Fiber</td>
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<tr>
<td>Aluminum Aramid Paper</td>
<td>Composites</td>
<td>Prepregs, Honeycomb Core Block Resin Systems for wide range of products</td>
<td><img src="image3.png" alt="Image" /></td>
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<tr>
<td>Carbon Fiber</td>
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<tr>
<td>Glass Fiber</td>
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<tr>
<td>Resins</td>
<td></td>
<td></td>
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<tr>
<td>Adhesives</td>
<td>Structures</td>
<td>Component assemblies for aerospace HexMC Parts Shaped/Machined Core</td>
<td><img src="image4.png" alt="Image" /></td>
</tr>
<tr>
<td>Honeycomb Prepregs</td>
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</table>
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

**Overall cure cycles**

~4 to ~8 hours (optimisation is key)

**Storage**

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Shelf life</th>
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<tbody>
<tr>
<td>+23°C</td>
<td>6 weeks</td>
</tr>
<tr>
<td>+5°C</td>
<td>6 months</td>
</tr>
<tr>
<td>-18°C</td>
<td>18 months</td>
</tr>
</tbody>
</table>

**Typical prepregs:**
high areal weights + full impregnation + low reaction enthalpy
The Value of Low Exotherm in Thick Parts

- Faster ramp rate
- Higher dwell temperature for shorter time
- Net reduction in cure cycle

Low exotherm matrix e.g. M19G

Standard exotherm matrix e.g. M9G
Major Features of Typical Wind Turbine Blades

- Root end
- Structure
- Process
- Surface
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**

- Laminate surface from standard prepreg: Pinholes. Surface must be repaired or gel coat must be used.

- Laminate surface from XF2P: No pinholes. Ready for painting.*

* After removal of release agent.
Surface Porosity from Shell Materials

Characterisation of XF2P Compared with Other Shell Materials

Direction of improvement
**XF2P: Cross-sectional Analysis**

- Standard triax laminate
  - surface layer defects

- Laminate using XF2P at surface
  - 1mm
Prepregs for the Load-carrying Structure
**Thick Glass Laminates using Prepregs**

Very low porosities from typical glass prepregs even in thick laminates

71 plies, 6cm
**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 mechanical performance is consistently greater
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

Prepreg mechanical performance is consistently greater.
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**

<table>
<thead>
<tr>
<th>Carbon spar cap:</th>
<th>25 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>length</td>
<td>0,40 m</td>
</tr>
<tr>
<td>width</td>
<td>22 mm</td>
</tr>
<tr>
<td>thickness</td>
<td>43</td>
</tr>
<tr>
<td>Number of plies</td>
<td>M9.6/32%/500+8P/C</td>
</tr>
<tr>
<td>Material</td>
<td>UD prepregs are ideally suited to automated layup</td>
</tr>
</tbody>
</table>

AC controlled room 25°C 40% RH

Heated mould

UD carbon prepreg

Exotherm peak 105°C

Laminate temperature

Mould temp

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

- Fabric
  - 3 plies of BB820

Foam and UD prepreg layers

- UD prepreg
  - 20 plies of M9.6F/32%/1600+CV/G
**Co-infusion: Case Study, Infusion Process**

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

<table>
<thead>
<tr>
<th></th>
<th>FV (%)</th>
<th>Porosity (%)</th>
<th>Tg (°C)</th>
<th>Cure cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>50</td>
<td>Side</td>
<td>Top</td>
<td>6hrs 90°C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0,7</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Middle</td>
<td>Middle</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1,5</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bottom</td>
<td>Bottom</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>75</td>
<td>75</td>
<td></td>
</tr>
</tbody>
</table>

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
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