Recent Developments in Materials and Processes for Blades at Hexcel

by Chris Shennan

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Sandia Wind Turbine Blade Workshop 2012
Agenda

- Introduction
- Prepreg resin systems for wind energy
- Prepregs for the surface
- Prepregs for thick load-carrying structures
  - Effect of architecture on porosity
- Use of prepregs for construction of spar caps
  - Conventional, pre-cured
  - New: co-infused and co-cured
- Conclusions
Introduction to Hexcel

The company
Hexcel in wind energy
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 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 resin systems for wind energy

Current resin systems
Systems for low exotherm
Next generation systems
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)

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

- **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
The Trend to Lower Exotherm, 1995-2012

Latest prepreg matrices minimise reaction exotherm allowing short cure cycles of thick structures
Next Generation Resin Systems

An improved (prepreg) matrix should have the following properties:

- Low cure temperature
- Fast cure
- Long outlife
- Low exotherm
- Superior static and dynamic mechanical properties
- Low cost
Next Generation Resin Systems

Recent developments have yielded the following

- Cure: 70°C ~10 hrs; 80°C ~6 hrs; 120°C <1 hr
- Outlife > 2 months
- Exotherm ~100 j/g
- Static mechanical properties as M9G
- Dynamic mechanical properties under evaluation
- Product form as current prepregs/ semipregs
- As easily manufactured as current M9G family prepregs

Provisional data
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

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
Prepregs for Thick Load-carrying Structures
Thick Glass Laminates using Prepregs

Very low porosities can be achieved from glass prepregs in thick laminates with optimised prepreg architecture.
**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 technology
Porosity <<1%

Optimised architecture in carbon UD prepregs consistently gives low porosity
Thick Carbon Laminates – Optimised Architecture

Before cure

54 plies UD 600gsm
(3.2 cm after cure)

During cure

Maximum temperature = 128°C

After cure

Maximum temperature = 128°C
**Thick Carbon Laminates – Optimised Architecture**

Even in the thickest laminates, optimised architecture consistently gives low porosity.
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>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon spar cap: length</td>
<td>25 m</td>
</tr>
<tr>
<td>width</td>
<td>0.40 m</td>
</tr>
<tr>
<td>thickness</td>
<td>22 mm</td>
</tr>
<tr>
<td>Number of plies</td>
<td>43</td>
</tr>
<tr>
<td>Material</td>
<td>M9.6/32%/500+8P/C</td>
</tr>
</tbody>
</table>

**Heated mould**

**Mould temp**

AC controlled room
- 25°C
- 40% RH

UD prepregs are ideally suited to automated layup

**Exotherm peak 105°C**

**Laminate temperature**

**Mould temp**
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

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

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

Cure cycle: 6hrs 90° C

Co-infusion simplifies the production process, combining the best features of prepreg and infusion materials.
**Co-infusion: Case Study, Porosity**

3x Infusion fabrics

Porosity assessment

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum void</td>
<td>&lt;0.85 mm²</td>
</tr>
<tr>
<td>Porosity</td>
<td>0.7-1.5%</td>
</tr>
</tbody>
</table>

20x M9.6F/32%/1600+CV/G

3x Infusion fabrics
Co-infusion: Case Study, Compression

Compression 0°

Strength (MPa)

<table>
<thead>
<tr>
<th></th>
<th>Non-normalised</th>
<th>Normalised</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infusion</td>
<td>800</td>
<td>600</td>
</tr>
<tr>
<td>Prepreg</td>
<td>1200</td>
<td>1000</td>
</tr>
<tr>
<td>Co-infusion</td>
<td>800</td>
<td>600</td>
</tr>
</tbody>
</table>

* ISO 14126

Modulus (GPa)

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<tr>
<th></th>
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<th>Normalised</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infusion</td>
<td>50</td>
<td>30</td>
</tr>
<tr>
<td>Prepreg</td>
<td>60</td>
<td>40</td>
</tr>
<tr>
<td>Co-infusion</td>
<td>50</td>
<td>30</td>
</tr>
</tbody>
</table>
Conclusions

Prepregs can be tailored for optimal wind blade manufacture

- Reaction exotherms can reduce to <100 j/g
- Cure temperatures can reduce to 70-80°C
- 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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