Characterization of Prepreg Materials for Wind Turbine Blades

Chris Shennan
9 May 2013
Agenda

- Hexcel company profile
- Background to prepregs in wind energy
- Prepreg characterisation
  - Surface prepregs (XF2P)
  - Structural prepregs (matrix system, M79)
- Combinations of prepregs with infusion: co-infusion
- Conclusions
Company Profile

- Technology leader in advanced composites
- Serving commercial aerospace, space & defense and industrial
- Net Sales 2012: $1.58 Billion
- 5,000 employees worldwide
- 19 manufacturing sites (including JV in Malaysia)
- Headquarters in Stamford, CT, USA
- Listed on New York and Paris Stock Exchanges
Background

Prepregs in Wind Energy
Typical Prepreg Systems in Wind Energy

**Typical resin systems**

- M9G  310 J/g
- M9GF  230 J/g
- M19G  160 J/g

**Cure temperature ~100-120°C**

**UD Products**

- Carbon 500-600 g/m²
- Glass 1000-3000 g/m²

**Overall cure cycles**

~4 to ~8 hours (optimisation is key)

**Typical prepregs**

- high areal weight + moderate cure temperature + 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
Features of Typical Wind Turbine Blades

- **Structure:**
  - Spar cap
  - Shear web
  - Shell

- **Root end**

- **Surface**

- **Process**
Prepreg Characterisation

This presentation will focus on the following

Surface and shell prepreg
- Characterisation of a surface prepreg that obviates an additional gel coat

Structural prepreg for large/ thick sections
- Characterisation of a new structural prepreg system, M79, that combines:
  - Low temperature cure
  - Low exotherm
Characterisation of a Shell Prepreg: HexPly XF2P
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

Painting makes the gel coat redundant as a surface finish system

This process can be simplified by using specific shell prepregs such as HexPly XF2P

- To build the aerodynamic shell surface
- To eliminate the gel coat
Conventional Shell Construction, with Gel Coat
XF2P – Gel Coat-free Surface Finish

HexPly M9.6/ 43%/ LBB1200 + CV/ G

No gel coat needed

Blade Mould

Prepreg

XF2P layer
**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

Surface technology drives >99% improvement
XF2P: Cross-sectional Analysis

Standard triax laminate

Surface layer defects

Laminate using XF2P at surface

1mm
Characterisation of Prepreg Matrices: M79

*Designed for Structural Applications*
M79

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

- Cure: 70°C ~10 hrs; 80°C ~6 hrs; 120°C <1 hr
- Outlife > 2 months
- Exotherm ~100-120 j/g
- Static mechanical properties as current M9G family prepregs
- Product form as current prepregs/ semipregs
- Manufacture: standard process, as current M9G family prepregs
M79 Compared with Conventional Systems

Wind Energy Matrix Exotherm as Function of Cure Temperature

- Typical LRI systems
- M9 family
  - 1995
  - 1998
  - 2002
  - 2005

Exotherm J/g vs. Cure temp °C
Reduction in Prepreg Exotherm, 1995-2013

Latest prepreg matrices minimise reaction exotherm allowing short cure cycles of thick structures
# M79: Example of Mechanical Test Data

<table>
<thead>
<tr>
<th>Test &amp; Direction</th>
<th>Measurement</th>
<th>70 °C Cure</th>
<th>M9 Historical</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. of specimens</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Tensile 0°</td>
<td>Strength (MPa)</td>
<td>8</td>
<td>469</td>
</tr>
<tr>
<td></td>
<td>Modulus (GPa)</td>
<td>8</td>
<td>21.2</td>
</tr>
<tr>
<td>Compression 0°</td>
<td>Strength (MPa)</td>
<td>10</td>
<td>413</td>
</tr>
<tr>
<td></td>
<td>Modulus (GPa)</td>
<td>10</td>
<td>21.0</td>
</tr>
<tr>
<td>ILSS (45°, 4-ply)</td>
<td>Strength (MPa)</td>
<td>20</td>
<td>46.7</td>
</tr>
</tbody>
</table>

Normalized results are in bold

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

Overall, M79 mechanical test data compares favourably with conventional (M9) systems
# M79: Example of Mechanical Test Data

<table>
<thead>
<tr>
<th>Test &amp; Direction</th>
<th>Measurement</th>
<th>80 °C Cure</th>
<th>M9 Historical</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. of specimens</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Tensile 0°</td>
<td>Strength (MPa)</td>
<td>456</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Modulus (GPa)</td>
<td>19.1</td>
<td>0.3</td>
</tr>
<tr>
<td>Compression 0°</td>
<td>Strength (MPa)</td>
<td>394</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Modulus (GPa)</td>
<td>20.5</td>
<td>1.0</td>
</tr>
<tr>
<td>ILSS (45°, 4-ply)</td>
<td>Strength (MPa)</td>
<td>39.5</td>
<td>1.1</td>
</tr>
</tbody>
</table>

|                  |                  |            |               |

Test results for HexPly M79/43%/LBB1200+CV/G cured at 80 °C

Overall, M79 mechanical test data compares favourably with conventional (M9) systems
M79 and Co-infusion

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

M79 simplifies co-infusion when making large structures because it cures at 70-80°C (i.e. same temperature for both infusion and prepreg matrices)
Wind Blades: M79 co-cured in an Infused Shell

1. Prepreg spar cap laid up on dry reinforcements
2. Dry reinforcement co-infused with prepreg followed by co-cure
Co-infusion: Case Study after Demoulding

The finished 4x2m laminate

Co-infusion simplifies the production process, combining the strengths of prepreg and infusion materials

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>Middle</td>
<td>Middle</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bottom</td>
<td>Bottom</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>0,7</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1,5</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>75</td>
</tr>
</tbody>
</table>

Cure cycle: 6hrs 90°C
Conclusions

- **Prepregs** are used for both structural and surface applications in wind blade construction.

- **The surface of XF2P laminates** have been characterised for surface defects.
  - Defects can be reduced by >99% to give a paint ready surface.

- **M79**, a new matrix for wind blades, has been characterised after cure at 70° and 80°C.
  - Cure reaction enthalpies are 100-120 j/g, reducing from 350 j/g over the last 15 years.
  - Static mechanical properties compare favourably with standard materials.

- **The low cure temperature of M79** helps enable co-infusion of prepreg with dry reinforcements, thus combining the best features of each process.
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.