Multi-layer carbon stacks for large wind turbine rotor blades

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Hexcel Company Profile

- Technology leader in advanced composites
- Serving commercial aerospace, space & defense and industrial
- Net Sales 2013: $1.68 Billion
- 5,300 employees worldwide
- 19 manufacturing sites (including JV in Malaysia)
- Headquarters in Stamford, CT, USA
- Listed on New York and Paris Stock Exchanges
Hexcel in Wind Energy

➢ Market Leader for prepreg materials in Wind Energy
  ▪ Annual capacity of > 20 000 t
  ▪ Global Supplier for over 20 years; Production sites in USA, China, Europe
  ▪ Product development in close cooperation with key accounts; Technical Support and R&T

➢ Carbon materials for load carrying structures in large wind turbine rotor blades
  ▪ Cured Laminates and Prepregs for spar caps or reinforced shells

Carbon sheet materials for spar caps
Multi-layer approach for spar caps

Making use of individual ply functions of the following materials

- **HexPly® Carbon UD Prepreg – 600 gsm + grid**
  - 2 layer material
  - air-vent; UD reinforcement and bonding function

- **Polyspeed® Carbon UD Laminate – 600 gsm**
  - Pre-cured UD reinforcement; exo control, caul plate function

- **HexFIT® Glass Biax Semipreg – 600 gsm +/- 45**
  - air-vent; +/- 45 reinforcement and bonding function

Take advantage of individual ply functions
The air-vent function

Morphological comparison of multi-layer prepreg stacks and infusion part

- Homogeneous fiber area weight
- Low ply waviness
- Porosity in Biax +/-45°
- Very uniform fiber/matrix distribution
- Low porosity due to grid layer
- Good air-vent
- resin rich domains at infusion channels
- some 90° waviness
Multi-layer build on a micro scale

- **Layup 1**
  - Carbon UD Prepreg + grid

- **Layup 2**
  - Biax prone to entrap air at fiber crossings

- **Layup 3**
  - Polyspeed® Carbon UD Laminate to flatten a stack, caul plate function

Carbon laminate to increase process robustness and quality
Porosity of different part sections

Porosity in carbon areas is very low due to air-vent grid layer.
Multi-layer performance

➢ Wrong stack sequence leading to defects

Example: The absence of air vent scrim on C-Laminate / C-Prepreg interface leads to entrapped air.

Stack sequence is key for multi-layer build
Carbon multi-layer – interfaces by ILSS

Pure prepreg vs. alternating specimen build with pre-cured C-laminate

<table>
<thead>
<tr>
<th>test</th>
<th>layup</th>
<th>no. layers</th>
<th>product</th>
<th>direction</th>
<th>sequence</th>
<th>result</th>
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<tbody>
<tr>
<td>ILSS</td>
<td>C-Prepreg</td>
<td>4</td>
<td>UD600</td>
<td>0°</td>
<td>PPPP</td>
<td>70 MPa</td>
</tr>
<tr>
<td>ILSS</td>
<td>alternating</td>
<td>4</td>
<td>UD600+Polyspeed</td>
<td>0°</td>
<td>PPPL</td>
<td>68 MPa</td>
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<tr>
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<td>UD600+Polyspeed</td>
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<td>PLPL</td>
<td>61 MPa</td>
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<tr>
<td>ILSS</td>
<td>Block cut</td>
<td>-</td>
<td>UD600+Polyspeed</td>
<td>0°</td>
<td>PPPL</td>
<td>78 MPa</td>
</tr>
</tbody>
</table>

4 ply Prepreg - ILSS: 70 MPa

4 ply Prepreg & pre-cured - ILSS: 68 MPa

“Block cut” specimens, 2,4 mm - ILSS: 78 MPa

Highest ILSS for multi-layer material
Polyspeed® - function as caul plate

Left: C-laminate reduces defect size  Right: no C-laminate, defect visible

Wire test to display caul plate function
Polyspeed® - function as caul plate II

- A distortion (wire) in 90° direction causes a wavy prepreg stack.

- Introducing Polyspeed® pre-cured carbon UD laminate, waves are totally smoothened. Polyspeed ® functions as a build in caul plate.

Polyspeed reduces defect area and increases performance.
Polyspeed® - function as caul plate III

- Caul plate on top of the prepreg stack leads to plane surface, waves are present throughout the entire specimen cross section.

- Caul plate on top and C-laminate inside, waves are stopped at C-laminate.

Laminate improves fiber alignment in carbon spar caps
Carbon cube experiment

Introducing M79 - Low exotherm & low temperature cure epoxy resin to multi-layer concept
The Value of Low Exotherm in Thick Parts

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

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Cure Time (95%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>70°C</td>
<td>480min</td>
</tr>
<tr>
<td>80°C</td>
<td>240min</td>
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<tr>
<td>90°C</td>
<td>130min</td>
</tr>
<tr>
<td>100°C</td>
<td>75min</td>
</tr>
<tr>
<td>120°C</td>
<td>60min</td>
</tr>
</tbody>
</table>

Low exotherm matrix M79
Standard exotherm matrix M9
Carbon cube experiment - layout

- Low exotherm resin in a very thick carbon part dimensions 400 x 400 x 400 mm, **beyond existing applications**
- Material: M79 UD **600 gsm prepreg** with **air-vent grid** layer
- **695 plies** of HexPly® M79 carbon fiber prepreg
- Layup in tool (4 sides); cured in vacuum bag and press (top / bottom)

**Easy layup process of the 695 prepreg plies**
Carbon cube experiment – results I

Results after cure

- $T_{\text{max \, exo}} < 140 \, ^{\circ}\text{C} \, (\text{center}); \, T_{\text{surface}} < 90 \, ^{\circ}\text{C}$
- Once at $80^{\circ}\text{C}$, cure took 6 hours only
- All parts of the cube fully cured (calc.)
Carbon cube experiment – results II

- The very low exotherm (100 - 120 J/g) of M79 enables to cure thick sections at moderate temperatures
- Multi-layering of carbon prepreg with air-vent layers for easy processing and close to monolithic part character

You can see the cube on Hexcel’s booth at CAMX
Thank you!

Joerg Radanitsch - CAMX 2014

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