Fabrication of Continuous Glass Fiber/ Nylon6,6 Thermoplastic Composite with Improved Mechanical Properties

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Overview

• INVISTA - Our heritage and commitment to PA66
• Market drivers for composites
• Limitations of current composite technology
• Challenges to overcome
• Improvements in current technology
• Q&A
Heritage and commitment
INVISTA – History

- 75+ years in nylon intermediates technology
- More than 10,000 employees in 20 countries
- The world’s largest integrated producer of nylon 6,6 polymer and intermediates
- Launched engineering polymers business in 2009
- Subsidiary of Koch Industries, Inc.
  - Annual revenues of approximately $115 billion
  - About $65 billion in acquisitions and investments since 2003, including INVISTA and Georgia-Pacific
Market Drivers for Composites
• **Fuel Efficiency improvements driven by new CAFÉ standard:**
  - Desired goal – 60% improvement - 34.5 mpg to 54.5 mpg by 2025
    - Light weighting can potentially contribute up to 10-20% improvement

• **Improved balance of properties such as:**
  - Balance of Stiffness & Toughness for Safety applications

• **Design freedom and improved productivity through system integration**
Limitations of existing technologies

- Short fiber reinforced polyamides:
  - Limited Stiffness – 5% of steel
  - Strength and stiffness drop significantly at 50% RH condition
  - Impact strength is relatively low

- Continuous fiber/PA66 composite
  - Much better than Short glass fiber...however, Strength and modulus balance still needs further improvement.
  - Property drop still significant with moisture conditioning.

Efficient load transfer in continuous fiber composite is still a challenge
Designing for the Ideal Final solution

- A composite system where there is efficient load transfer from continuous fibers to polymer matrix.

- System which enables easy processing using conventional methods (injection molding, Compression molding, etc).

- Design freedom with ability to predict performance based on fundamental material characterization.

- Scalable solution to enable Value creation in the market place.
INVISTA’s approach
Approach to achieve Improved Load Transfer

• TORZEN® Resin
  - PA66 → Conventional PA66 resin
  - Mod. PA66 → PA66 resin modified to possess high flow characteristics

• Fiber
  - GF → Commercial glass fiber roving, compatible with polyamide

• Narrow UD Tape
  - Melt coating...following a similar path per our 2013 presentation, “Nylon 6,6 continuous fiber thermoplastics composite – evaluation of processing techniques for optimal performance”, Chul Lee et al., SPE ACCE 2013
Laminate Making Flow Chart

Narrow UD tapes for multi-directional TFP prepreg fabrication, 3-5 mm

TFP: Tailoed Fiber Placement

TFP: Stitch narrow UD tapes into multi-directional fabric

In-mold heating and cooling press

Upper mold half
Prepreg
Lower mold half

Laminate (0, 0/90 and quasi-isotropic)

Method was referenced from “Nylon 6,6 continuous fiber thermoplastics composite – evaluation of processing techniques for optimal performance”, Chul Lee et al., SPE ACCE 2013
Characterization & Method

- **Resin viscosity**
  - Capillary rheology test
  - Melt flow index (MFI), ASTM1238

- **Testing**
  - Tension, ASTM D3039
    - 0 deg laminate $\rightarrow$ 10” x 0.5” x 0.08”
    - 0/90 and quasi-isotropic laminates $\rightarrow$ 10” x 1” x 0.08”
    - Tab is not required if failure mode is acceptable
    - At least 5 specimens were tested
  - Void content, ASTM D2734
    - Specimen size 0.5” x 0.5” x 0.08”
    - At least 5 specimens were tested

- **Moisture conditioning**
  - 50%RH $\rightarrow$ 3 weeks in 80%RH chamber, 1 week in room condition
  - 100%RH $\rightarrow$ 6 months in water bath
Resin Viscosity

- Pellet moisture controlled at around 0.15%
- Mod. PA66 has lower viscosity
- Lower viscosity $\rightarrow$ Higher MFI
Resin Basic Mechanical Properties

- Mechanical properties remain constant
- Strain at yield did not change
- Polymer matrix properties did not change
Tensile Strength & Modulus – 0 Deg Laminate

- Improvement of 25%-30% in tensile strength → better fiber wetting
- Minor improvement in tensile modulus
- Fiber volume fraction 50%-55%, void <1%
- Lower standard deviation → more repeatable results
- Moisture gain of 50%RH sample about 0.4%
0 Deg Laminate – Failure Curve and Mode

Typical stress-strain curve, valid failure mode “XGM”

- X → explosive
- G → gage section
- M → middle
Tensile Strength & Modulus – 0/90 Deg Laminate

- Major improvement in tensile strength (3X) and modulus (2X)
- Fiber volume fraction 50%-55%, void <1%
- Low Moisture gain @ 50%RH sample – 90% retention of properties
Major improvement in tensile strength and modulus
Fiber volume fraction 50%-55%, void <1%
Higher standard deviation maybe due to fiber tow movement
Moisture gain of 50%RH sample about 0.46%
Designing parts with composites

Goal: Achieve same stiffness with PA66 composite as a metal part

<table>
<thead>
<tr>
<th>Material (condition)</th>
<th>PA66/ 30% GF (DAM)</th>
<th>PA66/ 30% GF (50% RH)</th>
<th>PA66/ 50% GF (DAM)</th>
<th>PA66/ 50% GF (50% RH)</th>
<th>Laminate, UD (DAM)</th>
<th>Laminate, UD (50% RH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Strength (Mpa)</td>
<td>200</td>
<td>130</td>
<td>250</td>
<td>190</td>
<td>920</td>
<td>820</td>
</tr>
<tr>
<td>Tensile Modulus (Gpa)</td>
<td>10</td>
<td>7</td>
<td>17</td>
<td>13</td>
<td>44</td>
<td>42</td>
</tr>
<tr>
<td>TS % Drop (wrt DAM)</td>
<td>-</td>
<td>-35%</td>
<td>-</td>
<td>-24%</td>
<td>-</td>
<td>-11%</td>
</tr>
<tr>
<td>TM % Drop (wrt DAM)</td>
<td>-</td>
<td>-30%</td>
<td>-</td>
<td>-24%</td>
<td>-</td>
<td>-4%</td>
</tr>
</tbody>
</table>
### Summary of Tensile Modulus Values: Experimental vs Predicted (DAM)

<table>
<thead>
<tr>
<th>Laminate Construction</th>
<th>Test Orientation</th>
<th>Experimental Result</th>
<th>Laminate Plate Theory</th>
<th>FEA Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 degree 0 degree</td>
<td>43.7</td>
<td>43.69</td>
<td>43.72</td>
<td></td>
</tr>
<tr>
<td>0 degree 90 degree</td>
<td>10.8</td>
<td>10.8</td>
<td>10.82</td>
<td></td>
</tr>
<tr>
<td>0/90 0 degree</td>
<td>23.6*</td>
<td>27.5</td>
<td>27.5</td>
<td></td>
</tr>
<tr>
<td>Quasi-Isotropic</td>
<td>21.2</td>
<td>21.7</td>
<td>21.72</td>
<td></td>
</tr>
</tbody>
</table>

* Lower experimental value possibly due to fiber movement

- Both the laminate theory and CAE simulation results are close to experimental results
- Key assumption of laminate plate theory - “perfect/complete bonding”
  - If good wetting of fibers is achieved, laminate plate theory/FEA simulation holds well
### Summary of Modulus Values: Experimental vs Predicted (50% RH)

<table>
<thead>
<tr>
<th>Laminate Construction</th>
<th>Test Orientation</th>
<th>Experimental Result</th>
<th>Laminate Plate Theory</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 degree</td>
<td>0 degree</td>
<td>42.3</td>
<td>42.3</td>
</tr>
<tr>
<td>0 degree</td>
<td>90 degree</td>
<td>9.03</td>
<td>9.0</td>
</tr>
<tr>
<td>0/90</td>
<td>0 degree</td>
<td>26.4</td>
<td>25.9</td>
</tr>
<tr>
<td>Quasi-Isotropic</td>
<td>0 degree</td>
<td>22.6</td>
<td>20.2</td>
</tr>
</tbody>
</table>

Both the laminate theory and CAE simulation results are close to experimental results, even for 50% RH samples.
Summary and Conclusion

• UD tapes made with TORZEN® PA66 resin formulation shows significant improvement in load transfer efficiency resulting in improved properties Vs typical PA66 and PA6 continuous fiber composites.

• Both CLPT and FEA results agree well (within 10%) with experimental results.
Q & A

Thank you for your attention
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