Topics Covered

• Types of Composite Materials
• Properties of Composite Materials
• Composite Manufacturing Processes
• Design, Manufacturing and Testing of the Composite MLB Helmet
Examples of Composite Sporting Goods

• Arrows
  – Increase stiffness to decrease energy loss
• Baseball and Softball bats
  – Durability, performance, sweet spot size, handle flex
• Hockey Sticks
  – Reduce weight, adjust flex or kick point
• Fishing rods
  – Lighter, increase sensitivity and adjust flex profile
• Tennis Rackets
  – Reduce weight, increase sweet spot
A composite material is a combination of two or more materials differing in form or composition that retains their identities.
Why Composites

• Anisotropic nature of composites – design to a direction or loading condition
• Good strength to weight ratio
• Versatile manufacturing processes
• Large amount of material combinations
• Aesthetics
Typical Components of the Composite

- Binder (Resin or Matrix)
  - Epoxy (Thermoset)

<table>
<thead>
<tr>
<th></th>
<th>Density (g/cc)</th>
<th>Modulus (Msi)</th>
<th>Tensile Strength (Ksi)</th>
<th>Elongation (%)</th>
<th>Cost ($/lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoxy</td>
<td>1.20</td>
<td>0.30 – 0.50</td>
<td>1.0 - 14</td>
<td>2 – 30</td>
<td>$5 - $20</td>
</tr>
</tbody>
</table>

- Reinforcement (Fiber)
  - Fiber Glass
  - Aramid
  - Carbon

<table>
<thead>
<tr>
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<th>Tensile Strength (Ksi)</th>
<th>Elongation (%)</th>
<th>Cost ($/lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E Glass</td>
<td>2.54</td>
<td>11</td>
<td>500</td>
<td>4.8</td>
<td>$ 1.00</td>
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<tr>
<td>Aramid</td>
<td>1.44</td>
<td>19</td>
<td>550</td>
<td>2.8</td>
<td>$ 18.00</td>
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<tr>
<td>Carbon</td>
<td>1.78</td>
<td>33 - 85</td>
<td>500 - 850</td>
<td>0.7 – 2.1</td>
<td>$13 - $100</td>
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</tbody>
</table>
Fiber Forms

• Continuous tow
  – Different yields (bundle size, g/1000m)

• Braid “socks”
  – Different diameter and thickness

• Woven
  – Different types for: processing, thickness, and aesthetics

• Prepreg – fiber with uncured resin
  – Unidirectional or woven
  – Very consistent: resin content and thickness
Cured Composite Properties

- Apply rule of mixtures for composite properties
- \[(\text{Volume Fraction fiber}) \times (\text{Property fiber}) + (\text{Volume Fraction resin}) \times (\text{Property resin}) = \text{Property of the Composite}\]
- Strength \((0.5 \times 500) + (0.5 \times 10) = 255\)

<table>
<thead>
<tr>
<th>Material</th>
<th>Density (g/cc)</th>
<th>Modulus (Msi)</th>
<th>Strength (Ksi)</th>
<th>Cost ($/lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Epoxy</td>
<td>1.55</td>
<td>16.50 – 40</td>
<td>250 - 450</td>
<td>$9.00 - $50</td>
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<tr>
<td>E Glass Epoxy</td>
<td>1.87</td>
<td>5.50</td>
<td>255</td>
<td>$ 3.00</td>
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<tr>
<td>Aramid Epoxy</td>
<td>1.33</td>
<td>9.50</td>
<td>280</td>
<td>$ 11.50</td>
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<tr>
<td>7075 – T6 Aluminum</td>
<td>2.82</td>
<td>10.0</td>
<td>86</td>
<td>$ 16.00</td>
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<tr>
<td>4150 Steel</td>
<td>7.89</td>
<td>30.0</td>
<td>280</td>
<td>$ 3.00</td>
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</table>
Wet lay-up Vacuum bag

- Cut woven material
- Wet out pattern
- Lay on release film
- Lay on bleeder cloth
- Lay on bag and seal
- Pull vacuum while resin cures
Resin Transfer Molding
Filament Winding
Roll Wrap
Bladder Molding

- Bladder molding - Pressure from the inside
  - Prepreg material is applied over a bladder
  - Preform is placed in a mold, bladder is inflated
  - Heat is applied to cure
Process Comparison

• Wet lay-up – Canoes, helmets
  – Good exterior finish, complex shapes, low cost

• Resin transfer molding – bats, canoe paddles
  – Good consistency, mid part cost and equipment investment

• Filament winding – bats, golf shafts
  – Lower material cost, multiple parts, high equipment investment

• Roll wrap – arrows, fishing rods, golf shafts, bats
  – Tubular parts, good consistency

• Bladder molding – bike frames, tennis rackets, golf shafts
  – Good exterior finish, higher part cost
100 MPH Composite MLB Helmet

• Timeline
  – First discussed the project fall of 2010
    • Had a big and heavy ABS helmet that passed
    • Goal: 30% lighter and 15% smaller
    • Stiffness seemed to help lower SI
  – First mold in house January 2011
  – First part tested March 2011 and passed
  – Did not get another to pass for 2 months
  – Presented new design to MLB in June 2011
  – Set up production and running November 2011
Determine Materials and Process

• Wet Lay-up Vacuum bag was chosen
  – Need for good exterior finish
  – Complex shape
    • Multiple piece mold to be able to remove the part

• Carbon fiber was chosen
  – Maximize stiffness
  – Minimize weight
  – Started with standard “off the shelf” woven carbon

• Epoxy resin was chosen
  – Good pot life
  – Ease of use
  – Very durable/tough system
Issues

• Weave did not conform to the complex shape
  – Developed a “looser” weave to be more pliable
  – Developed a thick material to reduce the number of patterns

• Surface finish was very poor
  – Started testing standard spray gel coats (polystyrene)
    • Too much smell
  – Development our own epoxy gel coat
    • Tougher and production friendly

• Difficult to get consistent vacuum
  – Development a box to put the mold with a reusable silicone bag

• Cycle time was too long
  – Tried different resin but nothing was as durability as the first resin
  – Started heating the box to decrease cure time
Helmet Lay-up

- Assemble Mold
- Apply gel coat
- Apply resin to weave
- Lay in weave
- Lay in peel ply
- Lay in perforated film
- Lay in bleeder cloth
- Seal bag
- Pull vacuum and heat

Left half of mold
Molded Helmet

- Remove from mold
- Trim perimeter
- Cut holes
- Sand
- Paint
- Insert pads
- Apply decals
Head Form to measure Peak “G” force and Severity Index
Future of Composites in Sporting Goods

• Helmets – lighter, dual ear
• More nano technology
• More cost effective non-destructive testing
• Lower cost materials and processes to make them more available to everyone
Summary

• With the anisotropic nature of composite a person can design the stiffness or strength in the direction or plane that is the most beneficial for a specific product

• Large amount of design options with different fibers, resins and fiber content enables a person to mix and match materials and processes for a given application