Engineered Structural Composites in Stiffness-critical Fuel Cell Applications

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Engineered Structural Composite (ESC) Molding Compounds

- High Levels of Reinforcement: Typically 50 – 66% by Weight

- Specialty / Exotic Resin Systems
  - Hybrid Vinyl Ester
  - Epoxy
  - Polyimide

- Unique Combination of Stiffness & Toughness
## ESC Materials – Typical Properties

<table>
<thead>
<tr>
<th>Material</th>
<th>% Reinforcement</th>
<th>Density (LB/IN$^3$)</th>
<th>Tensile Strength (PSI x E3)</th>
<th>Tensile Modulus (PSI x E6)</th>
<th>Flexural Strength (PSI x E3)</th>
<th>Flexural Modulus (PSI x E6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMC-8590 - Carbon</td>
<td>55%</td>
<td>0.053</td>
<td>36</td>
<td>7.0</td>
<td>80</td>
<td>5.0</td>
</tr>
<tr>
<td>QC-8800 - Glass</td>
<td>63%</td>
<td>0.068</td>
<td>50</td>
<td>3.8</td>
<td>85</td>
<td>3.0</td>
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<tr>
<td>SMC</td>
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<tr>
<td>Polyester - Glass</td>
<td>30%</td>
<td>0.066</td>
<td>12</td>
<td>1.7</td>
<td>26</td>
<td>1.6</td>
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<tr>
<td>Metals</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Al Die Cast</td>
<td></td>
<td>0.098</td>
<td>48</td>
<td>10.4</td>
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<td></td>
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<tr>
<td>Al Wrought</td>
<td></td>
<td>0.098</td>
<td>40</td>
<td>10.4</td>
<td></td>
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<tr>
<td>Mg Die Cast</td>
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<td>0.064</td>
<td>22</td>
<td>6.4</td>
<td></td>
<td></td>
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<tr>
<td>Steel 1008</td>
<td></td>
<td>0.280</td>
<td>48</td>
<td>30.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**ESC Materials**

**AMC-8590 - Carbon**
- % Reinforcement: 55%
- Density: 0.053 LB/IN$^3$
- Tensile Strength: 36 PSI x E3
- Tensile Modulus: 7.0 PSI x E6
- Flexural Strength: 80 PSI x E3
- Flexural Modulus: 5.0 PSI x E6

**QC-8800 - Glass**
- % Reinforcement: 63%
- Density: 0.068 LB/IN$^3$
- Tensile Strength: 50 PSI x E3
- Tensile Modulus: 3.8 PSI x E6
- Flexural Strength: 85 PSI x E3
- Flexural Modulus: 3.0 PSI x E6

**SMC**
- Polyester - Glass
  - % Reinforcement: 30%
  - Density: 0.066 LB/IN$^3$
  - Tensile Strength: 12 PSI x E3
  - Tensile Modulus: 1.7 PSI x E6
  - Flexural Strength: 26 PSI x E3
  - Flexural Modulus: 1.6 PSI x E6

**Metals**
- Al Die Cast
  - Density: 0.098 LB/IN$^3$
  - Tensile Strength: 48 PSI x E3
  - Tensile Modulus: 10.4 PSI x E6
- Al Wrought
  - Density: 0.098 LB/IN$^3$
  - Tensile Strength: 40 PSI x E3
  - Tensile Modulus: 10.4 PSI x E6
- Mg Die Cast
  - Density: 0.064 LB/IN$^3$
  - Tensile Strength: 22 PSI x E3
  - Tensile Modulus: 6.4 PSI x E6
- Steel 1008
  - Density: 0.280 LB/IN$^3$
  - Tensile Strength: 48 PSI x E3
  - Tensile Modulus: 30.0 PSI x E6

[Quantum Composites Logo]
ESC Application – Fender Support

- Lightweight
- High Stiffness
- Design Flexibility
- Parts Consolidation
ESC Application – Stern Drive

- Corrosion Resistance
- Parts Consolidation
- Impact Resistance
Structural Composite Application in Fuel Cells
Fuel Cell Power Plant - Major Systems

- Fuel Processor
- Power Section
- Power Conditioner
- Balance of Plant
ESC Application – Pressure Plates

Function
- Forms Termini of Power Section
- Aids in Aligning and Sealing Individual Cells
- Provides Point of Connection for Fluid Routing
- May Provide Point for Power Take-off

Performance Attributes
- High Flexural Stiffness
- Corrosion Resistance
- Function as Insulator
- Dimensionally Stable
ESC Application - Pressure Plates

Competing Materials

- Cast Stainless Steel or Anodized Aluminum
- Assemblies of Components
  - Machined rigid plate
  - Load distribution bars
  - Springs
- Engineering Thermoplastics
ESC Application - Pressure Plates

Manufacturing Challenges
- Tight Tolerances
- Thick Sections
- Controlling Fiber Volume / Orientation in Molded Part

ESC Advantages
- Design Flexibility / Improved Functionality
- Molded-in Tolerances
- Corrosion Resistant
- Low Creep Characteristics
- Ability to Control Fiber Orientation
- Lower Cost for Endplate Assembly
ESC Corrosion Resistance Data
ESC Creep Performance Data
Development Process for Structural Composite Applications
Goals

- Reduce Development Time
- Bring Credibility to Design
- Reduce Project Risk
- Optimize Part Design for...
  - Parts Consolidation
  - Total Cost
- Provide “Quick and Low Cost’ Testable Prototype Parts
Evaluate Program Targets

Material Requirements
- High Strength / Modulus
- Corrosion Resistance, Potential UL Recognitions, etc.

Performance Targets
- Deflection Requirements at Service Loads / Temperature
- Weight Reduction
- Equal or Improved Functionality

Part Costs
- Vs. Incumbent Design and Current / Potential Material(s)

Piece Price Including Mold Costs
- Number of Molds Required to Meet Production
COMPAREM™ Design Tool

- Determines Optimum Design with Optimum Material Choice

- Outputs are …
  - Wall Thickness
  - Rib Height
  - Cure Time
  - Part Costs
  - Tonnage
  - Press Size
Assemblies with Similar Strength & Stiffness

1.313 lbs. 1.925 lbs. 3.238 lbs.
28% SMC

0.852 lbs. 1.733 lbs. 2.585 lbs.
QC-8800

0.543 lbs. 1.733 lbs. 2.275 lbs.
AMC 8590

QUANTUM COMPOSITES
Review Initial Part Design

- For ...
  - Moldability
  - Tooling Issues

- Use COMPAREM Results to Finalize Design Direction
Charge & Flow Pattern Analysis

- Enables Determination of Proper Charge Placement Required to Achieve Flow and Fiber Orientation

- Benefits …
  - Determine Material Volume Needs
  - Part Strength
  - Shape of Charge

- Go-no-go Decision Point
Production Launch

- Use Engineered Charge Pattern
- Obtain Full Parts in 2 – 3 Shots … Not Days
Composite Pressure Plate Design Example
Advantages of ESC Materials

- Design Flexibility
- Corrosion Resistance
- High Strength
- High Impact Resistance
- High Strength-to-weight Ratio
- Low Coefficient of Thermal Expansion
- Electrical Performance – non-conductive
- Dimensional Accuracy – Molded-in Tolerances
- Improved NVH Characteristics
Conclusions

Commercialization is Imminent
– Various Demo Programs Underway
– Residential / Portable in ‘02
– Transit Busses in ‘03
– Automobiles in ‘04

Many Segments / Niche Applications
– Initial Penetration into Price Insensitive Segments
– Broaden Commercial Scope / Deepen Penetration
– Increased Demand Will Affect Mass Production
Conclusions

Keys for Fuel Cell Manufacturers
- Demonstrate Success Initially
- Validate Efficiency / Reliability
- Drive Costs Down
- Creative Marketing / Business Strategies to Create Volume

Keys for Component Suppliers
- Material Development / Specification
- Design for Manufacture
- Development of High Performance / Low Cost Components
- Collaboration with OEM’s / Key Players