Carbon Fiber SMC Technology for Lightweight Structures

Matt Kaczmarczyk | Senior Design Engineer
1310 South Valley Center Drive
Bay City, Michigan 48706-9798 USA
Phone: 989-922-3863 ext. 116
Fax: 989-922-3915
mkaczmarczyk@quantumcomposites.com

Tim Langschwager | Lead Development Chemist
1310 South Valley Center Drive
Bay City, Michigan 48706-9798 USA
Phone: 989-922-3863 ext. 120
Fax: 989-922-3915
tlangschwager@quantumcomposites.com
Outline of Presentation

• What is Forged Composite?
• Differences Between CF-SMC and Traditional SMC
• High Flow vs. Low Flow Molding
• Typical Mechanical Properties of CF-SMC
• Important Characteristics of CF-SMC
• CF-SMC Applications
• Processes Comparisons
What is Forged Composite?

- Forged Composites: Term for compression molded CF-SMC
- Manufactured by Quantum Composites
- Headquartered in Bay City, Michigan
CF-SMC First Branded as “Forged Composites” – October 2010 Paris Auto Show

March 2012 Geneva (Aventador J)  
April 2012 Beijing (Urus)

Courtesy: Dr. Paolo Feraboli – Automobili Lamborghini Advanced Composites Structures Laboratory
Carbon Fiber Sheet Molding Compound

- Glass fiber SMC has been around since the 1960’s
- In 1987 Quantum developed epoxy 3k carbon fiber molding compound
- CF-SMC have been in use since early 1990’s
- What is unique about CF-SMC?
  - Quasi-Isotropic properties
  - Excellent for fastener-intensive and stiffness dominated parts
  - Carbon fiber reinforcement
  - High fiber content: $V_f\ 40\%+ / W_f\ 50\%+$
Carbon Fiber Sheet Molding Compound

Traditional SMC:
Sheet Molding Compounds (SMC) have traditionally been a low-performance process:

- Glass fiber
- Low fiber content: $V_f 18\%+ / W_f 25\%+$
- Low mold coverage / high flow
- Typically polyester resin
- Higher specific gravity

CF-SMC:
Feedstock material is chopped carbon fiber with resin
They are similar to prepreg in principle, but not in practice
We define Advanced Compression Molding to differentiate it from the traditional Compression Molding if:

- Carbon fiber
- High fiber content: $V_f 40\%+ / W_f 50\%+$
- Typically vinyl ester or epoxy resin but also BMI and phenolic
- Lower specific gravity
Advanced Compression Molding

- Ability to use the CF-SMC in a repeatable and predictable way to form unique applications
  - Minimum molded thickness as low as 0.035 in. (1 mm)
  - Reduced variability in strength
  - Co-mold with selective UD reinforcement
- Understanding the requirements is the key to material selection
  → Excellent for fastener-intensive and stiffness-dominated parts
Advanced Compression Molding

Example Fabricated (Welded) Steel Tubing

Compression Molded CF-SMC

Structural features such as ribs and gussets can easily be molded for acceptable and even matched performance.
Advanced Compression Molding

• Matched-mold process

Figure 1. Mold is closing

Figure 2. Mold is opening after cure
High Flow Molding

Similar to traditional SMC - fiber “orientation” is not controlled

1. Cut the material
2. Weigh the charge
3. Prepared Charge
4. Load the Charge

Courtesy: Premix
Low Flow Molding

Similar to traditional lay-up - fiber “orientation” is more controlled

Material is precisely cut and placed into mold
Material flow and charge pattern can effect mechanical properties.
Creating a uniform direction of fibers does not necessarily translate into improved strength.
Flow fronts and fiber bunching creating weak areas in the coupons/parts.
High Flow vs. Low Flow Molding

High Flow

Low Flow
High Flow vs. Low Flow Molding

High flow specimen showing fiber bunching at fracture area (Edge Effect at end of flow)

Low flow specimen showing a more uniform fiber displacement resulting in elevated strength properties.
Comparison of Material Performance

**Tensile Strength vs. Tensile Modulus**

- **Quasi-Iso Tape**
- **Ti-6-4** (15.2, 174.0)
- **AL6061-T6**
- **Glass SMC**

**Reference Materials**

**Discontinuous Carbon Fiber Molding Compound**
Fiber Aspect Ratio

- Higher Fiber Aspect Ratio =
  - Higher performance
  - Lower COV strength values
  - Higher notch sensitivity

3K – 3,000 filaments per tow (roving)

12K – 12,000 filaments per tow

50K – 50,000 filaments per tow

3k=100 tows

12k=25 tows

50k=6 tows
Comparison of Carbon Fiber Tow (CF-SMC)

Tensile Strength comparison of ASTM Method

*ASTM D-638 in the graph above uses “as molded” net shape test specimen. ASTM D3039, D5766, and D6742 use specimen machined from molded plaques.
Comparative Properties of CF-SMC

- Moduli as high as prepreg quasi baseline
- Unnotched strengths lower than prepreg quasi baseline
- Compression higher than tension
- Open-hole strengths more appealing
- Higher CoV in strength and modulus

→ Excellent for fastener-intensive and stiffness-dominated parts

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>30</td>
<td>2%</td>
<td>10.0</td>
<td>0%</td>
<td>30</td>
<td>30</td>
<td>10.0</td>
<td>30</td>
</tr>
<tr>
<td>Quasi-isotropic fabric T700/977-6</td>
<td>108</td>
<td>4%</td>
<td>6.0</td>
<td>5%</td>
<td>60</td>
<td>70</td>
<td>4.9</td>
<td>45</td>
</tr>
<tr>
<td>3k CF-SMC</td>
<td>47</td>
<td>10%</td>
<td>5.0</td>
<td>10%</td>
<td>37</td>
<td>52</td>
<td>5.4</td>
<td>37</td>
</tr>
<tr>
<td>12k CF-SMC</td>
<td>29</td>
<td>18%</td>
<td>5.5</td>
<td>27%</td>
<td>29</td>
<td>42</td>
<td>6.0</td>
<td>33</td>
</tr>
<tr>
<td>50k CF-SMC</td>
<td>22</td>
<td>20%</td>
<td>5.5</td>
<td>20%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Comparative Fatigue Curves

S-N curve

UTS (psi)

Life (Cycles)

3K CF-SMC
12K CF-SMC
AL6061-T6

Tension – Tension 3Hz
Notched Behavior

- Specimens containing open holes fail both in the net and gross section
- Typical fastener hole size ¼-inch diameter hole

3k
- 98.6% failed at hole
- 1.4% failed away from hole

12k
- 26.4% failed at hole
- 73.6% failed away from hole
Effects of Defects

- Difficult for Non Destructive Inspection: signal is noisy
- Ultrasonic scans reveal areas of weak reflection or “Hot Spots” – not necessarily defects
Modulus Variability

- Modulus measurements either via strain gage or extensometer
- High variability encountered (approx 19%) much higher than strength variability (approx 10 %)
- Experiments using gage lengths of 0.125, 0.25, 0.5, 1.0 and 2.0 in.
- Also 1.0 in. extensometer
- Longer gages do not yield better measurements
- Measurements vary along length and across width of specimens
Modulus Variability

- Digital image correlation (DIC)
- Black speckles are applied to a white background on one side of a specimen
- Images are taken during testing by a pair of digital cameras
- Post processing allows to measure full field strain
- Measurement shows local variations
Fiber Orientation

- High degree of influence on mechanical properties, stiffness
- Changes with high flow vs. low flow molding process and part geometry
- Molded specimens will give high mechanical values due to favorable fiber orientation.
- With cut specimens, the fibers are cut in the gage length reducing the strengths by about 25-30% from molded specimens.

Fibers tend to orient in the direction of flow and along the cavities edge.

ASTM D 638 MOLDED SPECIMEN

Fibers are random, but cut at the parts edge.

ASTM D 3039 CUT FROM PANEL
Outline of Presentation

• What is Forged Composite?
• Differences Between CF-SMC and Traditional SMC
• High Flow vs. Low Flow Molding
• Typical Mechanical Properties of CF-SMC
• Important Characteristics of CF-SMC
• CF-SMC Applications
• Processes Comparisons
CF-SMC Applications

Carbon-Fiber Sheet-Molded Composite Underbody Diffuser for Nissan GTR

**Challenge**
Lower cost, parts consolidation

**Solution**
- Lower part cost vs. prepreg parts
- Corrosion resistance
- High stiffness
- Good impact strength
- Dimensional stability
- Ability to mold in ribs, bosses, changes in thickness (e.g., for attachment points)
CF-SMC Applications

Carbon-Fiber Sheet-Molded Composite Monocoque Tube and Suspension Arm for Lamborghini Siesto Elemento

Challenge
Lower cost, cycle time

Solution
• Much lower part cost vs. prepreg parts
• Lightweight
• High stiffness / strength
• Faster cycle time than RTM
• Higher volume compression molded
• Hybrid structures (e.g., Continuous + Discontinuous Fibers)
CF-SMC Applications
Additional CF-SMC Applications

Carbon fiber hood inner structure
http://www.sae.org/mags/sve/12288/

Carbon fiber fender support
Composite Fabrication Processes (thermoset)

- Injection Molding
- RTM
- Compression Molding (CF-SMC)
- Transfer Molding
- Injection Molding
- Autoclave / Vacuum Bag
- Hand Lay-up
- Spray-up

Production Volume vs. Tooling Cost
Thank you!