Advances in Compression Molding
Unidirectional & Discontinuous Carbon Fiber Thermoset Composite Technologies

Engineered Composites
Matthew Kaczmarczyk
Market Manager
Aerospace / Defense, High Performance Automotive

Tim Langschwager
Research and Development Manager
Presentation Summary

- Applications and advantages of using compression molded carbon fiber sheet molding compounds in automotive applications

- Challenges of using chopped fiber materials in automotive applications such as identifying defects, predictability of performance and possible sources of variation.
SMC (Sheet Molding Compound)

Manufacturing Process: Continuous process
Glass, carbon, basalt fibers fed (continuous or chopped) into resin system
Resin paste + chopped glass sandwiched between 2 film layers
Finished product = continuous sheet
Unidirectional and mat products available
Carbon Fiber Sheet Molding Compound

• Glass fiber SMC has been around since the 1960’s

• In 1987 Quantum Composites an A. Schulman Company 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

21 lbs

8 lbs

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

Patterns are cut manually or automatically and then stacked/arranged in a specific configuration (optimal final part performance) in the fixed, lower mold half.

Upper mold half moves down and compresses charge pattern. The material flows (not a stamping process).

**Advantages**

- Very large parts (> 250 lbs.) can be produced with minimal fiberglass degradation
- Optimal fiber orientation in critical locations achievable through charge pattern (no injection gates)
- Combinations (i.e., mat, unidirectional) can be utilized together for ideal part strength
- Well suited for molded-in inserts, design flexibility, and thickness variations within the part
- High flow due to heat/pressure combination
- An economical choice for moderate (< 10,000) to very large volumes using single or multiple cavity tooling
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
High Flow vs. Low Flow Molding

- 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.

Load vs. Displacement Data

<table>
<thead>
<tr>
<th>Thickness (in)</th>
<th>Max Stress (ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Flow 1</td>
<td>0.153</td>
</tr>
<tr>
<td>High Flow 2</td>
<td>0.151</td>
</tr>
<tr>
<td>Low Flow 1</td>
<td>0.176</td>
</tr>
<tr>
<td>Low Flow 2</td>
<td>0.168</td>
</tr>
</tbody>
</table>

Tensile Strength

Tensile Modulus
High Flow vs. Low Flow Molding

Surface crack developing

Max strain near failure: 11403 us  
*Max strain of specimen: 11403 us

High Flow

Max strain near failure: 15589 us  
*Max strain of specimen: 15831 us

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)
- Glass SMC
- AL6061-T6

**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
Comparison of Carbon Fiber Tow (CF-SMC)

*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

Tension – Tension 3Hz

UTS (psi)

Life (Cycles)

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

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

- 98.6% failed at hole
- 1.4% failed away from hole
- 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
CF-SMC + Unidirectional Applications
CF-SMC + Unidirectional Applications
CF-SMC + Unidirectional Applications
Composite Fabrication Processes (thermoset)

Production Volume

Tooling Cost

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

Engineered Composites
Matthew Kaczmarczyk
EC Market Manager
Aerospace / Defense, High Performance Automotive

Tim Langschwager
Research and Development Manager

Our definition of success is helping you achieve yours.