A New Milestone in Carbon Fiber Sheet Molding Compound

A. Duraisamy1*, L. Kaptur2, V. Ugresic1, A. Hrymak3, F. Henning4

1Fraunhofer Project Centre, 2520 Advanced Ave, London, Ontario, Canada N6M 0E1
2Dieffenbacher North America Inc., 9495 Twin Oaks Drive, Windsor, Ontario, Canada N8N 5B8
3Faculty of Engineering, University of Western Ontario, London, Ontario, Canada,
4Department of Polymer Engineering, Fraunhofer Institute for Chemical Technology ICT, Germany

Abstract

Large tow carbon fibers are enabling carbon SMC products to be adopted by the automotive industry for a reasonable cost. The challenge is to determine an efficient way to process the large tows during compounding that enables complete realization of the mechanical properties. The Fraunhofer Project Centre together with Dieffenbacher have developed such a processing system and integrated it into the compounding step of SMC production. It is now possible to achieve significant improvement in mechanical properties compared to the Carbon-SMC products available in the market. Zoltek 50K tow fibers and Polynt Vinylester resin was used for this study. Up to 40% by volume of fiber content was achieved. Unlike most Carbon-SMC in the market, the in-house compounded material had very good flow and filled parts were achieved with 25% mold coverage. Overall, the material shows great potential in terms of high performance SMC applications for the automotive industry.

Introduction

Sheet molding compound (SMC) is a versatile long fiber thermoset composite process where fibers of 0.5 inch to 2 inch are randomly oriented and sandwiched between two thin layers of resin spread over carrier films. With the aid of compression force, the resin is impregnated for complete wet out of the fiber. The compounded material is generally allowed to mature between 2 to 5 days before molding. Due to its good flow-ability and class-A surface finish, SMC has been in use for many secondary structure applications.

Since the introduction of SMC material into the automotive industry, many different resin systems have been added to the list of materials that can be processed through SMC technology for achieving better mechanical, chemical or fire retardant properties. With recent race to achieve low density SMC material which can be used for structural applications, carbon fiber has come into the picture of SMC processing.

Carbon fiber provides much higher mechanical properties in comparison to conventional glass fibers that are used in SMC processing but the main drawback of carbon fiber is the cost. With replacement of glass with carbon, it is not just the properties of the final product but also the cost of the product increases greatly and makes it challenging to adopt for the automotive industry.
Typically the cost of fibers increases as the tow size decreases. One way to reduce the carbon fiber cost is to use large tow spools for the SMC production. However, use of large tow carbon fibers results in mechanical properties which are lower values than glass, due to improper resin impregnation resulting in dry spots and resin rich regions which ultimately affects the strength of the material.

One way for complete realization of mechanical properties by carbon fiber is to break the large tow carbon fibers to smaller tow sizes before they are impregnated with resin in the SMC line. Dieffenbacher with the Fraunhofer Project Centre (FPC) has developed a fiber spreading system which can fulfill this task. It is an easy integration to the existing SMC line which can break the large 50K tow fibers to 12K or lower.

Experiment

Fiber Spreader

The fiber spreader is a subsystem integrated into the compounding section of the SMC line. It works together with the fiber chopping system to spread open the large fiber tows into smaller tows. The present prototype is capable of producing sheet widths up to 50cm.

SMC Compounding

Dieffenbacher Direct-SMC (D-SMC) line at the FPC was used to produce the carbon SMC material that are discussed in this paper. Zoltek 50K, PX35 fibers and Polnyt HS X4885-70 resin coupled with DION 31100-00 hardener was used for making the SMC material. The resin paste was mixed using a 2HP dispenser with 2.5” saw tooth blades. Two different fiber types based on the fiber shape were used and three different batches were compounded, in which one batch of non-spread material was compounded as a control. 50%wt fiber loading was used in all the three batches. The paste was mixed for 10mins after adding all the additives. The SMC was compounded at an elevated temperature of 40°C. The compounded material was stored for maturation for a period of 48 hrs before molding. The formulation for the resin blend is listed in Table 1 and the overview of all the three batches in Table 2. The inhibitor was diluted using styrene to a 12.5% solution and then added to the resin. Figure 1 to 3 illustrate more on the compounding trail.

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>PHR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vinyl Ester Resin</td>
<td>HS X4885-70</td>
<td>100.00</td>
</tr>
<tr>
<td>Vinyl Ester Thickener</td>
<td>31100-00</td>
<td>13.33</td>
</tr>
<tr>
<td>Peroxide</td>
<td>Trignox C</td>
<td>1.50</td>
</tr>
<tr>
<td>Wetting Agent</td>
<td>BYK W996</td>
<td>2.50</td>
</tr>
<tr>
<td>Inhibitor</td>
<td>pBQ</td>
<td>0.40</td>
</tr>
<tr>
<td>Mold Release</td>
<td>BYK P9085</td>
<td>4.00</td>
</tr>
</tbody>
</table>
Table 2: Overview of compounded material

<table>
<thead>
<tr>
<th>Fiber Type</th>
<th>Spread/Non-spread</th>
</tr>
</thead>
<tbody>
<tr>
<td>PX35 – 15T11 (50%wt)</td>
<td>Spread</td>
</tr>
<tr>
<td>PX35 – 15W11 (50%wt)</td>
<td>Spread</td>
</tr>
<tr>
<td>PX35 – 15W11 (50%wt)</td>
<td>Non-spread</td>
</tr>
</tbody>
</table>

Figure 1: (a) Resin is supplied through the lower doctor box; (b) Spread CF is getting impregnated with the resin; (c) Non-spread CF is being chopped and falls on the resin film; (d) Compounded material is cut to smaller charges before maturation.
Figure 2 shows that the 50K tow fibers are broken down to much smaller tow sizes which results in complete impregnation of the resin. On the contrary, non-spread SMC, Figure 3, showed lot of dry spots due to the size of the tows that prevent the resin to penetrate completely and achieve full fiber impregnation. It was also noticeable that in case of non-spread CF SMC, due to the large tow carbon fibers the fibers were not completely covering the sheet width resulting in randomized resin rich regions.

**Compression Molding**

The sheets were cut to required weights in order to mold the material. Dieffenbacher Compress Plus, 2500T press was used for this process, where 457 x 457mm hard chrome
polished shear edge tool was used to make the plaques. Charges were cut to 95% coverage (440 x 440 mm). The mold temperature was set to 150⁰C and cured for 180sec at 100bar pressure. At 95% coverage, 2 sheets of charge were required to produce panels of around 2.5mm in thickness. The force profile and the speed profile used during the molding is given in Table 2 and 3.

<table>
<thead>
<tr>
<th>Position (mm)</th>
<th>Speed (mm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>40</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time (sec)</th>
<th>Force (KN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2090</td>
</tr>
<tr>
<td>180</td>
<td>2090</td>
</tr>
<tr>
<td>181</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 3: Speed profile for mold closing

Table 4: Force profile for molding

![Figure 4: (a) Charges cut to 95% coverage and stacked together; (b) Charge is placed in the plaque tool; (c) Cured part; (d) Part after demolding and labelling](image)

Mechanical Testing

From each plaque molded, 4 samples of flexural and tensile specimens were cut using waterjet machining. Out of the 4 samples two were cut at 0⁰ and two at 90⁰. The tests were
conducted on a MTS universal testing machine according to standards ISO 527 and ISO 14125.

Figure 5: Template for specimen cutting

Results and Discussions

Mechanical Test Results

The samples were cut and tested as per ISO standards. Waterjet machining was employed for this purpose. Two different fiber geometries (T – which has a rope like geometry and W – which has a ribbon like geometry) were tested, and each was spread, compounded and molded. Additionally one more batch of non-spread (using the T fibers) was molded to understand difference between mechanical properties achieved with spread versus non spread carbon fiber for understanding the improvement in mechanical properties due to spreading. The results are plotted in the graph as shown below.

In the graphs shown, first two sets of bars are the spread carbon-SMC results and the third is the non-spread batch. The last black bar indicates the properties of commercially available Polynt SMCarbon, a (Vinylester system). From the tensile properties measured, 300% improvement in tensile strength of the material was achieved with spreading. Furthermore the spread batch outperforms commercialized SMCarbon material. Similarly flexural strength of spread material showcases significant improvements when compared to non spread fiber.
Figure 6: Tensile strength and modulus graph

Tensile Strength

- Material: Spread - W11 50%wt
  - 0deg: 161.03 MPa
  - 90deg: 184.48 MPa

- Material: Spread - T11 50%wt
  - 0deg: 118.90 MPa
  - 90deg: 164.45 MPa

- Material: Non spread - T11/NS 50%wt
  - 0deg: 53.45 MPa
  - 90deg: 41.25 MPa

- Material: Polyt SM Carbon 24 12K 50%wt
  - 0deg: 110.00 MPa

Tensile Modulus

- Material: Spread - W11 50%wt
  - 0deg: 32.49 GPa
  - 90deg: 30.51 GPa

- Material: Spread - T11 50%wt
  - 0deg: 23.81 GPa
  - 90deg: 30.74 GPa

- Material: Non spread - T11/NS 50%wt
  - 0deg: 15.16 GPa
  - 90deg: 6.51 GPa

- Material: Polyt SM Carbon 24 12K 50%wt
  - 0deg: 25.00 GPa

Figure 6: Tensile strength and modulus graph
Carbon spreading based on sizing

Zoltek produces carbon fibers with 3 different sizing content (1.5%wt, 1%wt and 0.75%wt). These different sizing contents of Zoltek PX 35 fibers were tested to understand the effectiveness of spreader with respect to the sizing content in the carbon tows. Figure 8 shows how each fiber sizing was broken down in the spreader. It is clear from the images that as sizing content decreases the spreading is improved.
Figure 8: (a) Chopped 50K fibers; (b) 1.5%wt sizing fibers after spreading; (c) 1%wt sizing fibers after spreading and (d) 0.75%wt sizing fibers after spreading

Demonstration Part

After initial study using the plaque tool, it was interesting to see how the material would behave for more complicated geometry. The seat tool available at the FPC was used for this purpose. Charges were placed in the mold to achieve and completely filled parts were produced. The molded parts showed waviness in sections of thickness variation but overall it did not show any blistering and was easy to demold. Lower charge coverages were also tested and it was proven that even with less part coverage with longer flow lengths, good filling and quality of the parts was achieved.
Conclusion

The paper demonstrates the ability of the new spreading system developed by Dieffenbacher and the Fraunhofer Project Center. Two different fiber geometries were used to produce molded parts and tested. The results revealed that the SMC produced using the new spreader system outperformed the commercially available Vinylester carbon SMC in the market and mechanical properties improved more than 250% in comparison to non-spread carbon SMC. Further study conducted based on the sizing of the fibers revealed that with decrease in sizing content the spreading of fibers improved.

In terms of future work, the material behaviour in much more complex shapes such as thin rib sections, as well as understanding of material flow after longer storage periods would be interesting to explore.

References

1. Hamid G. Kia. Sheet Molding Compounds Science and Technology


3. Polynt Composites, Compounds – Carbon Fiber products brochure