Filament Wound Graphite Fiber Reinforced Al & Mg Composites for High Specific Stiffness Structural Applications

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MMCC’s pressure infiltration technology (APIC™) produces Al & Mg matrix composites reinforced with woven fabrics and filament wound preforms made from high modulus graphite fiber. Applications requiring high specific stiffness, low CTE, and no out gassing are best suited for these composites. All components are custom engineered and suitability is determined on a case by case basis depending on part geometry and other application requirements. These materials can be used to replace steel, beryllium, aluminum, and other traditional parts where weight and structural/thermo mechanical performance are key technology drivers.

Woven fabric preforms typically require lower modulus fibers due to fiber breakage and are usually not the best choice for many high stiffness applications. Woven fabrics are also less forgiving in terms of manufacturability and are more specific to applications where minimal CTE control is needed. MMCC has focused on filament winding technology because of flexibility in fiber architecture and the relative lack of fiber damage during processing.

MMCC’s filament winding center is a McClean-Anderson “Super Hornet” 4-axis, 2 meter long wrapping bed with a 1 meter diameter cylindrical wrapping capacity. This facility is used for manufacturing panels and tubular structures and shapes ranging from ¾” to 40” diameter. DXF CAD files of custom engineered winding mandrels are imported. Composite Designer software is then used to optimize and configure the fiber winding program tailored to the application.

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1 Weaving involves over and under cross plying of fibers that require local bending of fiber tows. This leads to a reduction in tensile strength of composites manufactured from woven preforms.
MMCC uses lamination theory models to predict properties of various ply wrapping schemes when infiltrated with Al and Mg alloys. Measured elastic properties are in good agreement with lamination theory calculations and give us a high level of confidence in our prediction methods.

### Filament Winding Process

The properties of a high modulus graphite fiber (12k tow) often used for high specific stiffness applications are given below.

- $E_1$: 125 Msi
- $E_2$: 1 Msi
- $G_{12}$: 3.0 Msi
- $\nu_{12}$: 0.85
- $\alpha_1$: -1.5 ppm/°K
- $\alpha_2$: 12 ppm/°K
- $k_1$: 400 W/m°K
- $k_2$: 10 W/m°K

### Properties of Selected Filament Wound Ply Patterns for 50Vf % Gr Fiber Reinforced Al & Mg Composites

<table>
<thead>
<tr>
<th>Ply Pattern (Using 50Vf 125 Msi Fiber)</th>
<th>Tensile (Msi)</th>
<th>Modulus (Msi)</th>
<th>Shear Modulus (Msi)</th>
<th>CTE (ppm/°C)</th>
<th>Poissons Ratio</th>
<th>Density (g/cc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0° (uniaxial)</td>
<td>x</td>
<td>161</td>
<td>x</td>
<td>0.6</td>
<td>68</td>
<td>66</td>
</tr>
<tr>
<td>± 15°</td>
<td>x</td>
<td>98</td>
<td>x</td>
<td>3</td>
<td>55</td>
<td>52</td>
</tr>
<tr>
<td>± 15° + 20% Hoop</td>
<td>x</td>
<td>95</td>
<td>x</td>
<td>7</td>
<td>48</td>
<td>47</td>
</tr>
<tr>
<td>± 15° + 33% Hoop</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>42</td>
<td>40</td>
</tr>
<tr>
<td>± 30°</td>
<td>x</td>
<td>33</td>
<td>x</td>
<td>5</td>
<td>27</td>
<td>23</td>
</tr>
<tr>
<td>± 30° + 20% Hoop</td>
<td>x</td>
<td>50</td>
<td>x</td>
<td>31</td>
<td>30</td>
<td>28</td>
</tr>
<tr>
<td>± 30° + 33% Hoop</td>
<td>x</td>
<td>62</td>
<td>x</td>
<td>11</td>
<td>27</td>
<td>25</td>
</tr>
<tr>
<td>0° / 90°</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>37</td>
<td>36</td>
</tr>
<tr>
<td>0° / 90° ± 45°</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>27</td>
<td>25</td>
</tr>
</tbody>
</table>

**NOTE:** Al properties are calculated. Mg properties are measured.
Modulus vs. Hoop % for +/- 15 Degree Filament
Wound Composites (50Vf Fiber)

CTE vs. Hoop % for +/- 15 Degree Filament
Wound Composites (50Vf Fiber)

Modulus vs. Hoop % for +/- 30 Degree Filament
Wound Composites (50Vf Fiber)

CTE vs. Hoop % for +/- 30 Degree Filament
Wound Composites (50Vf Fiber)
By using filament winding, MMCC is able to manufacture composite structures with a 23% higher specific stiffness than Be, 0.3 ppm/K axial thermal expansion (parallel to the optical axis) and a transverse CTE matching SiC. Such a product is ideal for optical support structures, and optical benches.

Filament Wound Panel Ready for Infiltration

A mirror substructure for Si membrane attachment is currently under development. This technology when, developed for hybridization with CVD SiC semi-replica mirror front and back membranes, will result in the stiffest, lightest, most thermally stable mirror support known to the optical community.

Mg/Gr Mirror Support Structures

Summary:
- Measured data agrees well with lamination theory modeling.
- +/-15 + 20% hoop structures have the thinnest balanced panel section thickness available ~0.050” (1.3 mm). Axial and transverse stiffness values of 50 msi (345 gPa) and 18.3 msi (126 gPa) respectively. Corresponding CTE values are 0.3 ppm/K in the axial direction (parallel to the optical axis) and 2.7 ppm/K in plane.
- Hybrid materials that are axially stiffer than Be and CTE matched in the reflective plane to SiC are under development for optical structures.
- Quasi-isotropic ply lay-ups (+/-30 + 33%hoop) have low CTE (~1 ppm/K) in both directions and can be CTE matched to Zerodur or ULE.

For more information please contact us to discuss your application.

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