3M Advanced Materials Division

3M™ Nextel™ Spread tow: Enabling automated processing methods and unique composite constructions

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Experimental material – Any technical information, recommendations, and other statements contained in this document or provided by 3M personnel about experimental material are based on limited information and the accuracy or completeness of such information is not guaranteed.
Designing with oxide-oxide CMCs: Understanding the price-performance relationship in new fabric designs

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# Experimental, high denier fabrics with 3M™ Nextel™ 610

<table>
<thead>
<tr>
<th>Fabric Type</th>
<th>Input Yarn Nextel 610 denier (g/9000m)</th>
<th>Weave</th>
<th>Thread Count (ppi) (warp / fill)</th>
<th>Weight (oz/yd²)</th>
<th>Thickness (inch)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DF-11-27-1500</td>
<td>1500</td>
<td>8HS</td>
<td>27.5 / 27.5</td>
<td>11</td>
<td>0.012</td>
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<tr>
<td>DF-11-14-3000</td>
<td>3000</td>
<td>5HS</td>
<td>15 / 14</td>
<td>~11</td>
<td>~0.013</td>
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<tr>
<td>DF-11-10-4500</td>
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<td>5HS</td>
<td>10 / 9</td>
<td>~12</td>
<td>~0.014</td>
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<tr>
<td>DF-19-23-3000</td>
<td>3000</td>
<td>8HS</td>
<td>23.5 / 23.5</td>
<td>19</td>
<td>0.020</td>
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<tr>
<td>DF-24-8-10000</td>
<td>10,000</td>
<td>4HS</td>
<td>8 / 8</td>
<td>~ 22</td>
<td>~ 0.024</td>
</tr>
</tbody>
</table>

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Room temperature mechanical properties

Matrix: AXC-610 Alumina Silicate
Plys: 6-12
Laminate thickness: ~2.9 mm
Fiber content: ~40 vol%
Porosity: ~24%

Variation in mechanical properties is less than 10% for all weave types except 10,000 denier fabric
Cost reductions with higher denier fabrics

Significant cost reductions can be achieved with minimal variation in physical and mechanical properties.
Automated fiber placement

Cost effective composite fabrication demonstrated in the polymer matrix composite (PMC) industry

- Higher denier input
- Higher throughput fabrication
- Lower scrap rates

Images courtesy of COIC
COIC

Automated Fiber Placement of Ceramic Matrix Composites

COI Ceramics, Inc.
7130 Miramar Road
San Diego, CA

Steve Atmur, Andy Szveda

41st Annual Conference on Composites, Materials, and Structures
Cocoa Beach / Cape Canaveral, FL, January 23, 2017

This document does not contain "technical data" as defined in the ITAR, 22 CFR 120.10; or "technology" as defined under the EAR (15 CFR 730-774)

Woven tape

3M™ Nextel™ 610
1500 denier
Tape thickness: ~19 mil

Tow pregging

Automated fiber placement
Ox-Ox CMC manufacturing

Current model

Fiber manufacturing → Sizing application → Weaving → Sizing removal (Burn off)

Prepregging → Part layup → Firing

Spread tow enabled model

Fiber manufacturing → Fiber spreading → Sizing application

Automated processing

Tow pregging → Part layup → Firing

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Nextel Spread tow

Elliptical tow

Flat ribbon

10,000 denier

width 3.8 mm (0.15")
thickness 0.18 mm (7.0 mil)

20,000 denier

width 3.8 mm (0.15")
thickness 0.27 mm (10.7 mil)

width 7.6 mm (0.30")
thickness 0.10 mm (4.0 mil)

width 12.7 mm (0.50")
thickness 0.19 mm (7.6 mil)

Width and thickness are nominal and not for specification purposes. Thickness was measured under 0.6 psi with a pressure foot gauge.
Input cost reductions with spread tow

Price ($/lb) relative to DF-11

Fabric:
- DF-11-1500: 100%

Spread tow:
- 10,000 denier: 40%
- 20,000 denier: 20%
Tow uniformity

3M™ Nextel™ 610
10,000 denier

Representative tow images

<table>
<thead>
<tr>
<th>Width (mm)</th>
<th>5.7</th>
<th>7.1</th>
<th>7.8</th>
<th>9.2</th>
<th>10.7</th>
<th>12.3</th>
</tr>
</thead>
</table>
Height profile across the tow width

Optical interferometry

3M™ Nextel™ 610
10,000 denier
Strand strength – Comparison to standard roving

3M™ Nextel™ 610
10,000 denier

'Spread tow'
- Standard roving spread
- Sizing burned off
- Tow water sized

'Spread tow'
- Standard roving spread
- Sizing burned off
- Tow water sized
Strand strength – Quantifying tow damage

3M™ Nextel™ 610
10,000 denier

- Intentionally damaged’
  - In-line process damage to the spread tow from nonideal conditions
  - Appearance of fuzz, broken fibers
Sizing development

Key characteristics

- Matrix compatible
  - Soluble – Easily dissolves in matrix
  - Low charring characteristics – Removal of components such as waxes that burn poorly
- Bundling – Maintenance of uniform width
- Durability – Protect fibers during handling
- Flexibility

Spread tow enabled model

- Fiber manufacturing
- Fiber spreading
- Sizing application
- Sizing removal (Burn off)

Automated processing

- Tow pregging
- Part layup
- Firing
Possible sizing compositions

Typical sizings for a water based matrix:

- Water soluble polymers
  - Polyvinylpyrrolidone (PVP)
  - Polyvinyl alcohol (PVA)
  - Polyethylene glycol (PEG)
  - Polyethylene oxide (PEO)
  - Copolymers, blends of these
- Binders, additives
  - Sugars (sucrose, dextrose, etc)
  - Cell gum
  - Guar gum
  - Acacia gum
  - Carboxymethyl cellulose
  - Glycerol

Solvent based matrix (as disclosed in published art)

- Alcohols
- Aromatic hydrocarbons
- Aliphatic hydrocarbons
- Glycol ethers
- Halogenated hydrocarbons

Typical sizings for a solvent based matrix:

- Polyvinyl butyral (PVB)
- Acrylics
- Polyethylenes
- Silicones
- Polyesters
- Styrenes
- Acrylates
- Polymethylmethacrylate
- Polyisobutenes
- Polydecenes
- Polydimethylsiloxanes
Sizing and CMC performance

N610, 10k uni from spread tow
8 ply, 0/90 layup
Aluminosilicate (AS) matrix

Unnotched tension strength (ASTM D3039)
Fiber dominated

Interlaminar tensile strength (ASTM C1468)
Matrix dominated
CMC pore distribution via mercury porosimetry

Greater extent of porosity, specifically in the range of ~10 μm, with Sizing B
Microstructure mapping

N610, 20k uni from spread tow
12 ply, 0/90 layup
Sizing C, AS matrix

x-ray tomography

~2.3 mm
~14 mm
~50 mm
Examples of voids and delamination

~2.3 mm

~14 mm
Ox-Ox CMC manufacturing

Current model

- Fiber manufacturing
- Sizing application
- Weaving
- Sizing removal (Burn off)
- Prepregging
- Part layup
- Firing

Spread tow enabled model

- Fiber manufacturing
- Fiber spreading
- Sizing application

Automated processing

- Tow prepping
- Part layup
- Firing

Spread tow fabrics

- Weaving
- Prepregging
- Part layup
- Firing
Experimental spread tow fabrics

Plain weave

2x2 twill

Unidirectional

Input
- Nextel 610
- 10,000 denier
- Water soluble polymer sizing
- UD weft:
  - EMS Griltec K85 (copolymide)
  - 150 denier
  - 3/cm
## Spread tow fabrics

<table>
<thead>
<tr>
<th>Fabric</th>
<th>DF-11</th>
<th>Experimental</th>
<th>Experimental</th>
<th>Experimental</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiber</td>
<td>Nextel 610</td>
<td>Nextel 610</td>
<td>Nextel 610</td>
<td>Nextel 610</td>
</tr>
<tr>
<td>Denier, g/9000m</td>
<td>1,500</td>
<td>10,000</td>
<td>10,000</td>
<td>10,000</td>
</tr>
<tr>
<td>Weave</td>
<td>8HS</td>
<td>Plain</td>
<td>2x2 Twill</td>
<td>Unidirectional</td>
</tr>
<tr>
<td>Areal density, gsm (oz/in²)</td>
<td>370 (10.9)</td>
<td>280 (8.3)</td>
<td>280 (8.3)</td>
<td>145 (4.3)</td>
</tr>
<tr>
<td>Thickness, µm (mil)</td>
<td>254 (10.0)</td>
<td>262 (10.3)</td>
<td>267 (10.5)</td>
<td>150 (5.9)</td>
</tr>
</tbody>
</table>

Fabric properties are not for specification purposes
To learn more, contact:

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3M Advanced Materials Division
arbeaber@mmm.com

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