All-oxide ceramic matrix composites (OCMC) based on low cost 3M™ Nextel™ 610 fabrics

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Introduction

• Overview on production and characteristics of OCMC‘s based on 3M™ Nextel™ fabric Type DF11

• What happens with fiber and fabric during the production process

• Experimental 3M™ Nextel™ 610 fabrics

• OCMC‘s based on experimental 3M™ Nextel™ 610 fabrics and a matrix Al₂O₃/ZrO₂ (FW12), production and characterisation

• Complex parts made of OCMC

• Cost reduction using the new fabrics

• Summary
Overview of companies working since more than 10 years on OCMC’s based on 3M™ Nextel™ 610 fabric Type DF11

<table>
<thead>
<tr>
<th>Company</th>
<th>COI Ceramics (COIC)</th>
<th>Composites Horizons Inc. (CHI)</th>
<th>Walter E.C. Pritzkow Spezialkeramik (WPS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process technology</td>
<td>Autocalve</td>
<td>Autoclave</td>
<td>Open laminated press technology</td>
</tr>
<tr>
<td>Matrix</td>
<td>(\text{Al}_2\text{O}_3/\text{SiO}_2)</td>
<td>(\text{Al}_2\text{O}_3/\text{SiO}_2)</td>
<td>(\text{Al}_2\text{O}_3/\text{ZrO}_2) (FW12)</td>
</tr>
<tr>
<td>Sintering temperature</td>
<td>Unknown</td>
<td>Unknown</td>
<td>1200 °C</td>
</tr>
</tbody>
</table>

Literature:
- 3M™ Nextel™ Spread tow: enabling automated processing methods and unique composite construction
  Aaron Beaber et al., USACA Jan 23, 2018
- Oxide-Oxide Ceramic Matrix Composites – Enabling Widespread Industry Adoption
  Barrett Jackson et al., HTCMC 9, 2016
- Designing with oxide-oxide CMCs: Understanding the price-performance relationship in new fabric designs
  Aaron Beaber et al., USACA Jan 24, 2017
Processing of OCMC’s at WPS

- **Ceramic fiber fabric**
  - Desizing

- **Powder Al₂O₃/ZrO₂**
  - Slurry production

- **Water with organic binder**
  - Slurry infiltration with knife blade coating
  - Laminating on moulds
  - Drying at 70-100°C
  - Demoulding
  - Sintering at 1200°C
  - Machining and finishing

Standard layup with 3M™ Nextel™ 610 fabric DF11
Characteristics of OCMC (1)

Tensile strength

![Tensile strength chart]

- WPS pressed
- COIC
- CHI

Tensile modulus

![Tensile modulus chart]

- WPS pressed
- COIC
- CHI

Bending strength

![Bending strength chart]

- WPS open
- WPS pressed
- COIC
- CHI

Bending modulus

![Bending modulus chart]

- WPS open
- WPS pressed
- COIC
- CHI
Characteristics of OCMC (2)

ILSS (SBB)

- WPS pressed
- COIC
- CHI

ILSS [MPa]
Tensile strength and bending strength dependent upon the fiber volume content

OCMC based on DF11

- WPS open
- WPS pressed
- COIC
- CHI

OCMC based on DF11

- WPS open
- WPS pressed
- COIC
- CHI
What happens when a fabric layup filled with powder is pressed to high fiber volume content?

Nextel 610 fabric type DF11 warp/fill with powder, tensile stress at 1% hits

- as received
- pressed to 1,5 mm
- pressed to 1,25 mm

As received
Pressed to 1,5 mm
Pressed to 1,25 mm
Tensile strength of fabric 3M™ Nextel™ 610 type DF11 compared with bending strength of the composite FW12

- Tensile strength fabric (DITF) [kg/cm]
- Bending strength FW12 [MPa]
Experimental 3M™ Nextel™ 610 fabrics

<table>
<thead>
<tr>
<th>Fabric type</th>
<th>DF11-3000 5HS</th>
<th>DF13-4500 5HS</th>
<th>DF13-4500 4HS</th>
<th>DF13-4500 Twill</th>
<th>DF19-4500 8HS</th>
<th>10.000 Semi Uni</th>
<th>20.000 Semi Uni</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yarn type</td>
<td>Nextel 610</td>
<td>3000 Denier</td>
<td>4500 Denier</td>
<td>4500 Denier</td>
<td>4500 Denier</td>
<td>10000/1500 Denier</td>
<td>20000/1500 Denier</td>
</tr>
<tr>
<td>Weaving</td>
<td>5HS</td>
<td>5HS</td>
<td>4HS</td>
<td>Twill</td>
<td>8HS</td>
<td>UD</td>
<td>UD</td>
</tr>
<tr>
<td>Areal weight [g/m²]</td>
<td>390</td>
<td>500</td>
<td>496</td>
<td>501</td>
<td>682</td>
<td>393</td>
<td>590</td>
</tr>
<tr>
<td>Thickness heat cleaned [mm]</td>
<td>0,28</td>
<td>0,33</td>
<td>0,33</td>
<td>0,33</td>
<td>0,43</td>
<td>0,26</td>
<td>0,48</td>
</tr>
</tbody>
</table>
Composites with matrix $\text{Al}_2\text{O}_3/\text{ZrO}_2$ and experimental 3M™ Nextel™ 610 fabrics

<table>
<thead>
<tr>
<th>Fabric type</th>
<th>DF11-3000 5HS</th>
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<th>DF19-4500 8HS</th>
<th>10.000 Semi Uni</th>
<th>20.000 Semi Uni</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of plies</td>
<td>10</td>
<td>10</td>
<td>8</td>
<td>8</td>
<td>6</td>
<td>12</td>
<td>8</td>
</tr>
<tr>
<td>Fiber volume content [%]</td>
<td>38,5</td>
<td>41,4</td>
<td>39,6</td>
<td>40,0</td>
<td>39,9</td>
<td>39,0</td>
<td>37,5</td>
</tr>
<tr>
<td>Matrix volume [%]</td>
<td>33,1</td>
<td>30,6</td>
<td>29,8</td>
<td>27,8</td>
<td>32,1</td>
<td>30,8</td>
<td>30,7</td>
</tr>
<tr>
<td>Porosity volume [%]</td>
<td>28,2</td>
<td>28,0</td>
<td>30,6</td>
<td>32,2</td>
<td>28,0</td>
<td>30,2</td>
<td>31,8</td>
</tr>
<tr>
<td>Density [g/cm³]</td>
<td>2,74</td>
<td>2,75</td>
<td>2,69</td>
<td>2,75</td>
<td>2,83</td>
<td>2,79</td>
<td>2,78</td>
</tr>
<tr>
<td>Laminate thickness [mm]</td>
<td>2,63</td>
<td>3,1</td>
<td>2,57</td>
<td>2,6</td>
<td>2,57</td>
<td>3,3</td>
<td>3,17</td>
</tr>
<tr>
<td>Thickness per ply [mm]</td>
<td>0,263</td>
<td>0,31</td>
<td>0,32</td>
<td>0,325</td>
<td>0,428</td>
<td>0,275</td>
<td>0,396</td>
</tr>
</tbody>
</table>
SEM-micrographs of composites with experimental 3M™ Nextel™ 610 fabrics (1)

FW12-DF11-3000 5HS

FW12-DF13-4500 4HS

FW12-DF13-4500 5HS
SEM-micrographs of composites with experimental 3M™ Nextel™ 610 fabrics (2)

FW12-DF13-3000 Twill

FW12-DF19-4500 8HS
SEM-micrographs of composites with experimental 3M™ Nextel™ 610 fabrics (3)

FW12-10.000 Semi Uni

FW12-20.000 Semi Uni
Tensile tests on composites with matrix Al$_2$O$_3$/ZrO$_2$ and experimental 3M™ Nextel™ 610 fabrics
4-Point-bending tests on composites with matrix Al$_2$O$_3$/ZrO$_2$ and experimental 3M™ Nextel™ 610 fabrics
4-Point-bending on edge tests on composites with matrix $\text{Al}_2\text{O}_3/\text{ZrO}_2$ and experimental 3M™ Nextel™ 610 fabrics
Stress intensity factor and notch sensitivity on composites with matrix $\text{Al}_2\text{O}_3$/ZrO$_2$ and experimental 3M™ Nextel™ 610 fabrics
Short beam bending / interlaminar shear tests on composites with matrix $\text{Al}_2\text{O}_3/\text{ZrO}_2$ and experimental 3M™ Nextel™ 610 fabrics
Complex structures made of oxide-oxide CMC

Thrusters for a Fluidic Propulsion System™ for unmanned aerial vehicles from the company Jetoptera Inc.

Static mixer

Development and production done by COIC and CHI

Picture source: aviation international news
Cost reduction possibilities using experimental 3M™ Nextel™ 610 fabrics

Data bases: 3M
Summary

• Tensile strength and bending strength are independent of the fiber volume content when producing OCMC within the range of 38-46%

• Pressing to higher fiber volume content with powder based slurries will damage the fibers

• Fabrics based on higher denier rovings can be well infiltrated with the $\text{Al}_2\text{O}_3/\text{ZrO}_2$ (FW12) slurry

• With some of the experimental 3M™ Nextel™ 610 fabrics better characteristics in comparison to DF11 based OCMC‘s can be realized

• Estimated cost reduction using the experimental fabrics is more than 20%
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Thanks for your attention

OCMC-Thrusters for the „Fluidic Propulsion System™ from Jetoptera Inc.