Ceramic Matrix Composite Materials Guidelines for Aircraft Design and Certification

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JAMS 2018 Technical Review
May 23-24, 2018
Ceramic Matrix Composite Materials
Guidelines for Aircraft Design and Certification

• Motivation and Key Issues
  – Expanded use of CMCs in engine and other hot section applications
  – CMCs require their own set of rules separate from more established PMCs
  – No “fully approved” data in CMH-17
  – Similar complexity to PMCs in terms of anisotropy, fiber architecture, high strength/stiffness fibers, and production process sensitivity and variability, they are also different in many ways such as:
    ▪ Composite constituents
    ▪ Degradation, damage, and failure mechanisms
    ▪ High temperature life predictions
    ▪ High temperature bonding challenges
    ▪ NDI challenges
    ▪ Repairability
Development of Qualification Program

• **Technical Monitor**: Ahmet Oztekin

• **NIAR Contacts**: John Tomblin, Rachael Andrulonis, Matt Opliger

• **Industry Partners**: Axiom Materials (prepreg), AC&A (panel), 3M (fiber and fabric), several steering committee members

• **Overall Goals**
  – Primary goal: To develop a framework for the qualification of new and innovative composite material systems including guidelines and recommendations for their characterization, testing, design and utilization.
  – Secondary goal: To transition the test data and guidelines generated in this program into shared databases, such as CMH-17.
Technical Approach

- Develop a framework to advance CMC materials into the aerospace industry.
- Utilize the experience and framework of the NCAMP composite program as an example of process sensitive material characterization.
- Assess the validity with equivalency testing.

**TASK 1:** Establish Steering Committee

**TASK 2:** Develop Qualification Framework

**TASK 3:** Validate framework with selected CMC material

**TASK 4:** Establish statistical guidelines

**TASK 5:** Transition
  - Material property data
  - Guidelines

**Surveys:**
- December 2016
- February 2019
Task 1: Steering Committee

- Steering committee formed with interested individuals
- Kick-off meeting was held in December 2016, Monthly meetings
- Collaboration with CMH-17
- Includes participants from industry (Pratt & Whitney, Free Form Fibers, Honeywell, Rolls Royce, Boeing, GE, 3M) and government (NASA, AFRL, FAA)
- Review and provide feedback on qualification plan, documents and resulting data
  - Overall test plan
  - Material specification
  - Process specification
  - Pedigree/documentation
  - Data
  - Statistical analyses
NCAMP Portal

- All members of the Steering Committee have access
- Monthly meeting charts
- Documents for review
- Related research

http://www.niar.wichita.edu/ncampportal/CMC/tabid/177/Default.aspx
Task 2: Development of Qualification Program

GOAL: Generate the framework for a qualification test program including material and process specifications, test matrices, and documentation requirements.

Objectives:
• Select an established CMC material and process to initially develop this framework. The material will be selected with input from the steering committee.
• Determine the critical process parameters and how they affect material properties.
• Address quality aspects of the selected CMC process and the framework for a quality assurance program.
• Draft material and process specifications for selected CMC material. These will be very specific – material, material supplier, processing.
• Develop CMC test matrix including required physical and mechanical data.
• Generate substantial mechanical property test data necessary for development of statistical guidelines using accepted test standards for CMC materials.
Material Selection and Process

- Fiber Source: 3M Nextel 610 Fibers (Alumina)
- Weaver: Textile Products Inc (TPI)
- Prepreg Supplier: Axiom
- Panel Fabricator: AC&A

- Prepreg production and panel fabrication is ongoing
- Screening tests are concluding at NIAR
- Site visit/audit at Axiom took place in November 2017 – PCD has been signed
NCAMP Material Specification

NCAMP Process Specification

NCAMP Test Plan

NCAMP Data Analysis

STATUS
- Material selection complete
- Material Spec – complete
- Process Spec – complete
- Test Matrix – complete
- Test Plan – released
**Qualification Program**

**QUALIFICATION**

- **Axiom Ox/Ox Prepreg Qualification**
  - 3 Batches
  - Panel Fab at AC&A

- **Qualification Testing at NIAR**

**TEST**

- **Baseline Qualification Database**

**BUILD**

**EQUIVALENCY**

- **EQUIV. #1**
  - TBD

- **EQUIV. #2**
  - TBD

**ANALYZE/PUBLISH**

**Equivalency/Additional Testing**

* Outside of current project scope, but NIAR project deliverable will allow for equivalency process and additional testing for future use by any party with the appropriate equipment and process.

**NOTES**

- **Additional Builds**
  - Phase 1 = Equivalency: Standard equivalency matrix, 1 batch only.
  - Phase 2 = Additional Testing: Tests not part of qualification database
Test Plan Overview

• Resources:
  ▪ Steering Committee
  ▪ PMC NCAMP test matrix
  ▪ CMH-17 Volume 1 and 5
  ▪ DOT/FAA/AR-03/19
  ▪ DOT/FAA/AR-06/10
  ▪ DOT/FAA/AR-02/110

• Selected property and/or conditions for preliminary studies
Process Definition

PER ENVIRONMENTAL CONDITION AND TEST METHOD

Material Batch

Panel Manufacturing & Independent Cure and Sintering Process

Number of Specimens Required per Test Method & Environment

Batch 1

Batch 2

Batch 3

Panel 1

Panel 2

Panel 3

Panel 4

Panel 3

Panel 4

3 spec.

3 spec.

3 spec.

3 spec.

3 spec.

3 spec.

18 Specimens Total
## Lamina Level Mechanical Tests

<table>
<thead>
<tr>
<th>Layup</th>
<th>Test Type and Direction (See Note 9)</th>
<th>Property</th>
<th>Test Method</th>
<th>Number of Batches x No. of Panels x No. of Specimens</th>
<th>Test Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>[0]_{SS}</td>
<td>Warp Tension (See Notes 1, 7, 8, and 10)</td>
<td>Strength, Modulus, and Poisson's Ratio (RTD Only)</td>
<td>ASTM C1275 (RTD) ASTM C1359 (ETD)</td>
<td>3x2x3</td>
<td>3x2x3</td>
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<tr>
<td>[90]_{SS}</td>
<td>Fill Tension (See Notes 1, 7, 8, and 10)</td>
<td>Strength and Modulus</td>
<td>ASTM C1275 (RTD) ASTM C1359 (ETD)</td>
<td>3x2x3</td>
<td>3x2x3</td>
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<tr>
<td>[0]_{6S}</td>
<td>Warp Compression (See Notes 2, 7, 8, and 10)</td>
<td>Strength and Modulus</td>
<td>ASTM C1358</td>
<td>3x2x3</td>
<td>3x2x3</td>
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<tr>
<td>[90]_{6S}</td>
<td>Fill Compression (See Notes 2, 7, 8, and 10)</td>
<td>Strength and Modulus</td>
<td>ASTM C1358</td>
<td>3x2x3</td>
<td>3x2x3</td>
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<tr>
<td>[45/-45]_{2S}</td>
<td>In-Plane Shear (45/-45 Tension) (See Notes 3 and 8)</td>
<td>Strength and Modulus (RTD Only)</td>
<td>ASTM D3518</td>
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<td>3x2x3</td>
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<tr>
<td>[0]_{7S}</td>
<td>In-Plane Shear (V-Notch Shear) (See Notes 4 and 8)</td>
<td>Strength and Modulus</td>
<td>ASTM D5379</td>
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<td>[0]_{7S}</td>
<td>Interlaminar Shear (Double-Notch Shear) (See Note 5)</td>
<td>Strength</td>
<td>ASTM C1292 (RTD) ASTM C1425 (ETD)</td>
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<td>[0]_{28}</td>
<td>Interlaminar Shear (Short-Beam Strength) (See Note 6)</td>
<td>Strength</td>
<td>ASTM D2344</td>
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</table>
# Laminate Level Mechanical Tests

<table>
<thead>
<tr>
<th>Layup (See Note 12)</th>
<th>Test Type and Direction (See Note 10)</th>
<th>Property</th>
<th>Test Method</th>
<th>Number of Batches x No. of Panels x No. of Specimens</th>
</tr>
</thead>
<tbody>
<tr>
<td>[0]$_{7S}$</td>
<td>Flexure (See Notes 1, 9, and 11)</td>
<td>Strength and Modulus</td>
<td>ASTM C1341</td>
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<td>[0]$_{10}$</td>
<td>Interlaminar Tension (Trans-Thickness/ Flatwise Tension) (See Note 2)</td>
<td>Strength</td>
<td>C1468</td>
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<tr>
<td>[0/90]$_{5}$</td>
<td>Interlaminar Tension (Trans-Thickness/ Flatwise Tension) (See Note 2)</td>
<td>Strength</td>
<td>C1468</td>
<td>1x1x6</td>
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<tr>
<td>[0/90]$_{14}$</td>
<td>Interlaminar Shear (Short-Beam Strength)</td>
<td>Strength</td>
<td>ASTM D2344</td>
<td>1x1x6</td>
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<tr>
<td>[45/0/-45/90/-45/90]$_{5}$</td>
<td>Unnotched Tension (See Notes 3, 9, and 11)</td>
<td>Strength and Modulus</td>
<td>ASTM C1275 (RTD) ASTM C1359 (ETD)</td>
<td>3x2x3 3x2x3</td>
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<tr>
<td>[45/0/-45/90/-45/90]$_{5}$</td>
<td>Unnotched Compression (See Notes 4, 9, and 11)</td>
<td>Strength and Modulus</td>
<td>ASTM C1358</td>
<td>3x2x3 3x2x3</td>
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<td>[45/0/-45/90/-45/90]$_{2S}$</td>
<td>Open-Hole Compression (See Notes 5 and 11)</td>
<td>Strength</td>
<td>ASTM D6484</td>
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<td>Open-Hole Tension (See Notes 6 and 11)</td>
<td>Strength</td>
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<td>[45/0/-45/90/-45/90]$_{S}$</td>
<td>Filled-Hole Tension (See Notes 7 and 11)</td>
<td>Strength</td>
<td>ASTM D6742</td>
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<td>Single Shear Bearing (See Note 11)</td>
<td>Strength</td>
<td>ASTM D5961 (Procedure C)</td>
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<td>[45/0/-45/90/-45/90]$_{S}$</td>
<td>Tension After Impact (See Notes 8 and 11)</td>
<td>Strength</td>
<td>ASTM D7136 ASTM D5766</td>
<td>1x2x3 1x2x3</td>
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</table>
Other Test Types Included

- Uncured Physical Tests
- Cured and Sintered Physical and Thermal Tests
- Fluid Sensitivity Tests
  - Short beam strength on $[0]_{28}$
  - Includes extended contact, short duration and control tests
  - Post-immersion conditioning – require 60 minutes minimum at 1650°F
Task 4: Guidelines and Recommendations

GOAL: To provide guidelines to industry for the collection of statistically meaningful critical data that designers need to utilize CMC materials potentially including:

• Creation of a shared CMC database including test data, material and process specifications and statistical analysis methods.
• Development of handbook data and guidelines (i.e., CMH-17).
• Coordinate with other standards and specification organizations to develop specifications from this program.
## Status – Based on FY2017 Deliverables

<table>
<thead>
<tr>
<th>Activity</th>
<th>Target Date</th>
<th>Milestone / Deliverable</th>
<th>Complete?</th>
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</thead>
<tbody>
<tr>
<td>1.2 Industry Steering Committee</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>- Establish group of participants</td>
<td>12/15/2016</td>
<td>Milestone</td>
<td>✓</td>
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<tr>
<td>- Create online portal for document sharing and data repository</td>
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<tr>
<td>1.3 Preliminary drafts of qualification framework</td>
<td>6/30/2017</td>
<td>Deliverable</td>
<td>✓</td>
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<tr>
<td>- Material and process specifications</td>
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<td></td>
<td></td>
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<tr>
<td>- Test plan</td>
<td></td>
<td></td>
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<tr>
<td>- Conformity documentation</td>
<td></td>
<td></td>
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<tr>
<td>1.4 Qualification Audit</td>
<td>11/10/2017</td>
<td>Milestone</td>
<td>✓</td>
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# Status – Based on FY2017 Deliverables

<table>
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<tr>
<th>Activity</th>
<th>Activity Description</th>
<th>Target Date</th>
<th>Milestone / Deliverable</th>
<th>Complete?</th>
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<tbody>
<tr>
<td>1.1</td>
<td>Trial / Screening Studies (ongoing)</td>
<td>1/15/2018</td>
<td>Milestone</td>
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<td></td>
<td>- Perform physical and mechanical tests to assist in final test matrix development and selection of machining and NDI methods</td>
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<td></td>
<td></td>
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<tr>
<td></td>
<td>- Present data to FAA, Industry Steering Committee, NCAMP Partners</td>
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<tr>
<td>1.2</td>
<td>Qualification Material</td>
<td>2/1/2018</td>
<td>Milestone</td>
<td>Panels in process</td>
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<td></td>
<td>- Site audit complete (scheduled for 11/7-11/8/2017)</td>
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<td></td>
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<tr>
<td></td>
<td>- Panels built and delivered to NIAR</td>
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<tr>
<td>1.3</td>
<td>Qualification Testing</td>
<td>8/31/2018</td>
<td>Milestone</td>
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<tr>
<td></td>
<td>- Perform physical and mechanical testing on qualification panels.</td>
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<td></td>
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<tr>
<td></td>
<td>- Generate test data for qualification program.</td>
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<tr>
<td>1.4</td>
<td>Develop Statistical Guidelines based on qualification data</td>
<td>10/1/2018</td>
<td>Milestone</td>
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<td>1.5</td>
<td>NCAMP Reports on Qualification Data</td>
<td>12/31/2018</td>
<td>Deliverable</td>
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<tr>
<td></td>
<td>- Material technical report</td>
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<td></td>
<td>- Statistical analysis technical report</td>
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<td>1.6</td>
<td>CMH-17</td>
<td>2/28/2019</td>
<td>Deliverable</td>
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<td>- Submit content, data, and protocols to Composite Materials Handbook 17 (CMH-17)</td>
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<td>1.7</td>
<td>Final Report</td>
<td>2/28/2019</td>
<td>Deliverable</td>
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Looking forward

• Benefit to Aviation
  – Publically available CMC data linked to M&P specs
  – Addition to CMH-17 handbook
  – CMC – PCD and process spec guidelines

• Future needs
  – Validate qualification data with equivalencies
  – Trial studies needed:
    ▪ Processing effects on CMCs
    ▪ SiC/SiC or C/SiC composites
    ▪ Effects of thermal and environmental barrier coating