CMH-17 Volume 5
Ceramic Matrix Composites

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Overview

• CMH-17 Mission and Vision
• Format / Content / History Summary
• Volume 5
• Working Groups
CMH-17 Mission

The Composite Materials Handbook (CMH) organization creates, publishes and maintains proven, reliable engineering information and standards, subjected to thorough technical review, to support the development and use of composite materials and structures.

CMH-17 Vision

The Composite Materials Handbook will be the authoritative worldwide focal point for technical information on composite materials and structures.

- Volunteer organization that creates, publishes, and maintains engineering information and standards to support the use of composite materials and structures
- Statistically analyzed composite data and guidance
Structure of Handbook

- Volume 1  Polymer Matrix Composites: *Guidelines for Characterization of Structural Materials*
- Volume 2  Polymer Matrix Composites: *Material Properties*
- Volume 3  Polymer Matrix Composites: *Materials Usage, Design and Analysis*
- Volume 4  Metal Matrix Composites
- Volume 5  Ceramic Matrix Composites
- Volume 6  Structural Sandwich Composites (Initial Release)
1. Document “best practices” for CMC design, processing, and operation.

2. Document test and analysis methods that can be used to show compliance to civil and military aviation regulations.

3. Provide information that will help simplify the process of assuring that CMCs are safe for use in aviation.

4. Provide characterization, property, and performance data of current and emerging ceramic matrix composite systems.
Handbook History

2017  Release of Vol. 5A – CMH-17 Handbook
2013  Release of Vol. 6, 4B – CMH-17 Handbooks
2012  Release of Volumes 1-3 Rev G – CMH-17 Handbooks
2006  Transition from Army to FAA as Primary Sponsor
      Established Roadmap to New Composite Materials
      Handbook “Release G”
2004  Joint Meetings with CACRC, SAE-P17
2002  MIL-HDBK-17 Vol. 1F, 2F, 3F, 4A, 5
      Commercial Publication through ASTM
1999  MIL-HDBK-17 Vol. 2E, Vol. 4
1998  Joint Meetings with ASTM D-30
1997  MIL-HDBK-17 Vol. 1E, 3E
1996  CMC Coordination Group Formed
1993  MMC Coordination Group Formed
1990  First PMC Data Set Approved
1988  MIL-HDBK-17B Vol. 1 Release
1986  Secretariat Added
1978  Coordination Group Formed
1971  MIL-HDBK-17A Plastics for Aerospace Vehicles
1959  MIL-HDBK-17 Plastics for Air Vehicles
1943  ANC Bulletin 17 Plastics for Aircraft

Last CMC handbook issued
~15 years ago

PMC: Polymer Matrix Composites
MMC: Metal Matrix Composites
CMC: Ceramic matrix Composites
Ceramic Matrix Composite (CMC) Components
For Commercial Aircraft Require Certification

• CMC components have begun to enter service in commercial aircraft.

• A wide range of issues must be addressed prior to certification of this hardware.

• The FAA is working with the CMC community to identify and document best practices for means of compliance to the regulations.
Ceramic Matrix Composite (CMC) Components For Commercial Aircraft Require Certification

- The Composite Materials Handbook-17, Volume 5 on ceramic matrix composites has just been revised to support certification of CMCs for hot structure and other elevated temperature applications.

- The handbook supports the development and use of CMCs through publishing and maintaining proven, reliable engineering information and standards that have been thoroughly reviewed.

- Volume 5 contains detailed sections describing:
  - CMC Materials / Processing
  - Design / Analysis Guidelines
  - Testing Procedures
  - Data Analysis and Acceptance
The CMH-17 Organization

~ 400 total members on PMC, CMC, and MMC rosters

Handbook Chairs
Larry Ilcewicz, FAA
Curtis Davies, FAA

Executive Group
(PMC, MMC & CMC WG Chairs)

Secretariat
Wichita State University

CMC Coordination Group
Curtis Davies, FAA

PMC Coordination Group
Larry Ilcewicz, FAA
Curtis Davies, FAA

MMC Coordination Group
Brad Lerch, NASA

Permanent Working Groups

Data Review
Rajiv Naik, Pratt & Whitney

Design and Analysis
David Thomas, Rolls-Royce
Mitch Petervary, Boeing

Guidelines
Curtis Davies, FAA

Materials & Processes
Kaia David, Boeing
Doug Kiser, NASA GRC

Testing
Jennifer Pierce, UDRI
William Keith, Boeing
Greg Wilson, GE Aviation
Volume 5 Handbook Outline

• Handbook grouped into 4 sections – each linked to specific working groups
  – *Part A: Introduction and Guidelines*
    • Materials and Processes WG
  – *Part B: Design Supportability*
    • Design & Analysis WG
  – *Part C: Testing*
    • Testing WG
  – *Part D: Data Requirements and Data Sets*
    • Data Review WG
Linking CMH-17 to FAA Certification

Provide standardized data and information for acceptance by authorities by:

- Establishing Active CMC Working Groups
  - Meeting sessions for each WG
  - Regular WG Telecons
  - Continually review WG charters and make necessary changes/edits
  - Work on key tasks identified and review periodically

- Periodically holding coordination meetings to discuss critical issues
  - CLEEN consortium/Cocoa Beach meetings
  - Working group meetings in conjunction with other CMC events
Working Group Activities

• Materials and Processes
• Design and Analysis
• Testing
• Data Review
Goals:

- To provide information on the composition, fabrication, quality control, and characterization of CMC engineering materials and structures.

- To provide a comprehensive overview of ceramic matrix composite (CMC) technology, outlining the types of CMCs, commercial aircraft applications, benefits, methods of fabrication, quality control, and supportability.

- To define the essential elements of information on composition, structure, and processing of CMCs necessary to support design, selection, fabrication, certification, and utilization of CMC structures.

- To specify the methods and procedures to be used in the characterization of ceramic matrix composites, their coatings, and their constituents. Efforts will be coordinated with the Testing Working Group.
New or Revised M&P Sections

- CMC Systems: Processing, Properties & Applications
- Fiber / Reinforcement Types and Technology
- Interphase / Interface Technology and Approaches
- Fabrication and Forming of Fiber Architectures
- External Protective Coatings for Non-Oxide CMCs
- External Protective Coatings for Oxide CMCs
- Characterization Methods
- NDE Methods for CMCs
- Machining

- Quality Control of Production Materials and Processes
- Applications, Case Histories, and Lessons Learned

Chapter 3
Chapter 4
Chapter 5
New M&P Sections - examples
Goals:

- To provide information on design and analysis methods and options, the level of substantiation required, and presentation formats required in validation and certification processes.
- To ensure future relevancy of the handbook by maintaining an up to date survey of the current state of the art capabilities within the design, analysis and lifing communities for CMCs.

Challenges:

- Creating a document that contains meaningful and valuable content for both industry and government entities while honoring the highly proprietary nature of corporate design practices.
New Design & Analysis Sections

- Definition of Application & Design Requirements
- CMC Component Design and Analysis Considerations
- Verification by Analysis for Material and Component
Testing Working Group

Vision Statement:
• To be the primary and authoritative source for recommended/required methods for testing characterization of CMCs & their constituents

Goals:
• To identify appropriate existing consensus standard test methods (such as ASTM Standards) for CMCs and their constituent materials
• To assist in the identification/development of appropriate standard test methods for CMCs and their constituent materials, where no such standards exist
New Testing Sections

- Density
- Tensile Testing
- Shear Testing
- Notched Testing
New Testing Sections - examples

13.6 TENSILE TESTING

13.6.1 Applicability

Tensile properties are important to design as laminated ceramic matrix composites are prone to delamination cracking through the un-reinforced matrix, perpendicular to the plane of the fiber reinforcement. Of interest to designers are the strength, modulus, Poisson’s ratio, and strain to failure of the composite.

13.6.2 Test Methods

There are several ASTM and other standards for the measurement of tensile properties of ceramic matrix or other composite materials. Those references identified are listed in Table 13.6.1.

<table>
<thead>
<tr>
<th>Method</th>
<th>Title</th>
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</thead>
<tbody>
<tr>
<td>ASTM C1275</td>
<td>Monotonic Tensile Behavior of Fiber-Reinforced Advanced Ceramics at Ambient Temperature1</td>
</tr>
<tr>
<td>ASTM C1359</td>
<td>Monotonic Tensile Behavior of Fiber-Reinforced Advanced Ceramics at Elevated Temperature2</td>
</tr>
<tr>
<td>HSR-EPM -D-001-93</td>
<td>Monotonic Tensile Testing of Intermetallic Matrix and Metal Matrix Composites</td>
</tr>
<tr>
<td>ASTM D3039</td>
<td>Tensile Properties of Polymer Matrix Composite Materials</td>
</tr>
</tbody>
</table>

CMH-17:5A

13.9.2 Test Methods

There are several ASTM and other standards for the measurement of interlaminar shear properties of ceramic matrix or other composite materials. Those references identified are listed in Table 13.9.2.

<table>
<thead>
<tr>
<th>Method</th>
<th>Title</th>
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</thead>
<tbody>
<tr>
<td>ASTM C1292</td>
<td>Standard Test Method for Shear Strength of Continuous Fiber-Reinforced Advanced Ceramics</td>
</tr>
<tr>
<td>ASTM C1425</td>
<td>Interlaminar Shear Strength of 1-D and 2-D Continuous Fiber-Reinforced Advanced Ceramics at Elevated Temperatures</td>
</tr>
<tr>
<td>ASTM D346</td>
<td>Standard Test Method for In-Plane Shear Strength of Reinforced Plastics</td>
</tr>
<tr>
<td>ASTM D344</td>
<td>Standard Test Method for Short-Beam Strength of Polymer Matrix Composite Materials</td>
</tr>
<tr>
<td>ASTM D3518</td>
<td>Standard Test Method for In-Plane Shear Response of a Polymer Matrix Composite Material by Tensile Test of a 45° Laminate</td>
</tr>
</tbody>
</table>

13.11 NOTCHED TESTING

Notched testing of CMCs is often motivated by the desire to develop design strength values that address the presence of damage including manufacturing defects, impact damage, and structural penetrations. Using damaged based strengths can ensure robust designs.

13.11.1 Notched Test Methods

Currently, there are no test methods specifically written for testing CMCs with notches or damage. Yet, the methods written for PMCs can often be adapted for CMCs. Methods for PMCs include tests of laminates with holes and of laminates with damage, typically generated by controlled impacts. Table 13.11.1 provides a list of these test methods. They are frequently adapted for the notch testing of CMCs.

<table>
<thead>
<tr>
<th>Method</th>
<th>Title</th>
</tr>
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<tbody>
<tr>
<td>ASTM D5766</td>
<td>Open-Hole Tensile Strength of Polymer Matrix Composite Laminates</td>
</tr>
<tr>
<td>ASTM D6484</td>
<td>Open-Hole Compressive Strength of Polymer Matrix Composite Laminates</td>
</tr>
<tr>
<td>ASTM D6742</td>
<td>Filled-Hole Tension and Compression Testing of Polymer Matrix Composite Laminates</td>
</tr>
<tr>
<td>ASTM D7137</td>
<td>Compressive Residual Strength Properties of Damaged Polymer Matrix Composite Plates</td>
</tr>
</tbody>
</table>

13.11.2 Considerations for Notch Testing of CMCs

13.11.2.1 Environment and Life Testing

CMCs are used in temperatures and environments much different than standard laboratory conditions. It is often challenging to replicate these environments during testing yet it is important that they are considered. Chemical and physical reactions at the notch tip can significantly affect the performance of CMCs particularly for repeated loading and long duration exposures. Thus, for CMCs that are sensitive to environmental degradation, e.g. non-oxide CMCs in hot oxidizing environments, investigators may need to test notched specimens in fatigue or for long durations in the appropriate environments to establish their service capability.
Vision Statement:

• Formulate guidelines & requirements for submission (batch size, etc.), documentation, analysis, and review for all CMC data that are submitted for inclusion in the handbook.
• Review the data and the analysis of data sets that are submitted for inclusion in the handbook.
• Develop formats for presentation of data in the handbook and for its storage in electronic databases.
• Develop and document statistical methods for pooling and analysis of CMC data.

Key Issues:

• Export classification of data that is submitted to the handbook
• Storage and dissemination of ITAR data
• Appropriate electronic Database choice for data storage and dissemination (with export restricted access as needed)
• Sources of new CMC data
Currently not ITAR restricted

<table>
<thead>
<tr>
<th>Composite Name</th>
<th>Composite Description</th>
<th>Producer</th>
</tr>
</thead>
<tbody>
<tr>
<td>9/99 EPM SiC/SiC</td>
<td>Sylramic™/BN-Si/MI SiC</td>
<td>Ceramic Composite Products</td>
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<tr>
<td>Enhanced SiC/SiC</td>
<td>CG Nicalon™/Carbon/CVI SiC</td>
<td>COI Ceramics</td>
</tr>
<tr>
<td>Carbon/SiC</td>
<td>T300/Carbon/CVI SiC</td>
<td></td>
</tr>
<tr>
<td>Hi-Nicalon/MI SiC</td>
<td>Hi-Nicalon™/BN/MI SiC</td>
<td></td>
</tr>
<tr>
<td>AS-N720-1</td>
<td>Nextel 720/alumino-silicate</td>
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</tr>
<tr>
<td>Sylramic S-200</td>
<td>CG Nicalon™/BN/PIP Si₃N₄-SiC</td>
<td></td>
</tr>
</tbody>
</table>

- New CMC data to be included in future revisions
- Currently working with organizations to obtain data
New Data Review Sections

- Data Submission Requirements
- Calculation of Statistically Based Material Properties
- Statistical Methods for Material Equivalence and Acceptance
New Data Review Sections - examples
Summary

• The Composite Materials Handbook-17, Volume 5 on ceramic matrix composites has just been revised with significant new material useful as a guide for CMCs:
  – CMC Materials / Processing
  – Design / Analysis Guidelines
  – Testing Procedures
  – Data Analysis and Acceptance

• *Developed over a 5 year period with approximately 100 volunteers*

• WGs are currently seeking volunteers

• Input for future revisions

• **Publication – June 2017 through SAE International – VOLUME 5A**
Individuals interested in contributing to these groups should please forward their contact information to

Rachael Andrulonis (rachael@cmh17.org)

and/or talk to any Working Group member

Annual Meeting @ USACA – January 2018
Monthly Teleconferences for Working Groups and Coordination