11-6-2017

# Updated Composite Materials Handbook-17 (CMH-17) Volume 5 - Ceramic Matrix Composites

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CMH-17
COMPOSITE MATERIALS HANDBOOK

# UPDATED
# COMPOSITE MATERIALS HANDBOOK-17 (CMH-17)
# VOLUME 5 — CERAMIC MATRIX COMPOSITES


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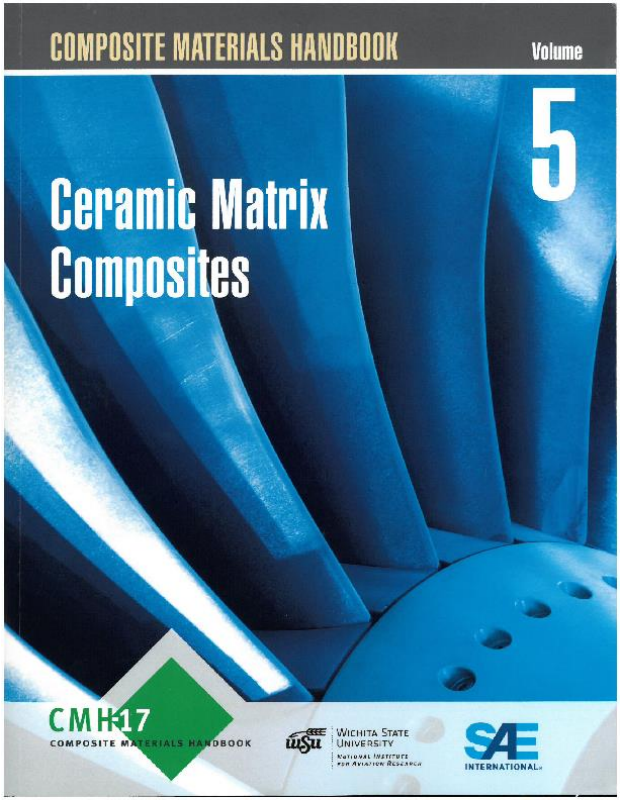
**Advanced Ceramic Matrix Composites: Science and Technology of Materials, Design, Applications, Performance and Integration**
***Engineering Conferences International,*** **Santa Fe, NM 11/06/2017**

# Overview

CMH-17
COMPOSITE MATERIALS HANDBOOK

- CMH-17 Mission and Vision
- CMH-17 Organization / Handbook Content / History Summary
- Volume 5
- CMC Working Groups
- Summary / Plans for the Future



# Composite Materials Handbook-17

## 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.**

# Composite Materials Handbook-17

## 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

# The CMH-17 Organization

CMH-17
COMPOSITE MATERIALS HANDBOOK

- ~ 160 volunteers attend PMC meetings
- ~ 300 total members on PMC, CMC, and MMC rosters

**Handbook Chairmen**
Larry Ilcewicz, FAA
Curtis Davies, FAA

FAA: Primary Sponsor

**Executive Group**
**(PMC, MMC & CMC WG Chairs)**

**Secretariat**
**NIAR/Wichita State University**

Professional Support

Date Established

**CMC Coordination Group**
Curtis Davies, FAA
CMC 1996

**MMC Coordination Group**
*Inactive*
MMC 1993

**PMC Coordination Group**
Larry Ilcewicz, FAA
PMC Curtis Davies, FAA 1978

Permanent Working Groups

**Testing**
Dan Adams, Univ. of Utah
John Moylan, ElementTesting

**Data Review**
John Tomblin, Wichita State Univ
Curtis Davies, FAA

**Supportability**
Joseph Rakow, Exponent Failure Anal.
Danielle Rocha, Embraer

**Materials & Processes**
Margaret Roylance, Nano Tech
Daniel Ruffner, Consultant

**Spacecraft**
Jeremy Jacobs, NASA
Jeff Eichinger, Boeing

**Statistics**
Beth Clarkson, Wichita State Univ
Curtis Davies, FAA

**Safety Management**
Larry Ilcewicz, FAA
Cindy Ashforth, FAA

**Guidelines**
Carl Rousseau, LM/Aero-FW
Steve Ward, UTAS

**Sandwich Composites**
Larry Gintert, Consultant
Melanie Violette, FAA

**Crashworthiness**
Allan Abramowitz, FAA
Mostafa Rassaian, Boeing

**Specialized Data Dev.**
*Inactive*

- **Two Active Coordination Groups.**
- **Each Coordination Group approves new additions to the handbook, and can elect to remove existing material from the handbook.**

https://www.cmh17.org/HOME/Organization.aspx

# Structure of Handbook

CMH-17
COMPOSITE MATERIALS 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*

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- Volume 4 Metal Matrix Composites

---

- **Volume 5 Ceramic Matrix Composites (recently updated)**

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- Volume 6 Structural Sandwich Composites (Initial Release)

*PMC Handbooks are Significantly More Established*

# CMC Components for Gas Turbine Engines:
## *Now Being Used in Commercial Aircraft*

CMH-17
COMPOSITE MATERIALS HANDBOOK


"A new epoch in high-temperature ceramic-matrix composites (CMCs) is upon us. Following three decades of research and billions of dollars of investment, CMCs are slated to appear in hot components in gas turbine engines for civilian aircraft.[1,2]"

**F. W. Zok, American Ceramic Society Bulletin, Vol. 95, No. 5**

# Handbook History

CMH-17
COMPOSITE MATERIALS HANDBOOK

**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

2012: Began Updating CMH-17 Vol. 5 (significant revision)

Previous CMC handbook issued ~15 years ago

PMC: Polymer Matrix Composites
MMC: Metal Matrix Composites
CMC: Ceramic matrix Composites

# What is the Importance of CMH-17 Volume 5— Ceramic Matrix Composites ?

CMH-17
COMPOSITE MATERIALS HANDBOOK

***Ceramic Matrix Composite (CMC) Components***
***<u>For Commercial Aircraft Require Certification</u>***

- **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.**

Federal Aviation Administration

# Certifying Composite Materials

CMH-17
COMPOSITE MATERIALS HANDBOOK

- **Composites are currently only certified as part of a *Product* (aircraft, engine, propeller).**

  ***There is no process to "certify" stand-alone composite materials for use in aviation products***

- **For CMCs: The FAA is currently defining means of compliance directly with applicant companies.**

Federal Aviation Administration

**For further details see Ref. 1**

# What is the Importance of CMH-17 Volume 5 – Ceramic Matrix Composites?

CMH-17
COMPOSITE MATERIALS HANDBOOK

- **Many steps are required to develop, validate, and document CMC materials for use in commercial aviation products. Our objective: CMH-17 Vol 5 will describe industry best practices / industry consensus standards.**


1) C. Ashforth, "Using CMH-17 in Certifying Aviation Products," Proceedings of the 40th Annual Conference on Composites, Materials and Structures, Cocoa Beach / Cape Canaveral, FL, *January 26, 2016.*

# Linking CMH-17 to FAA Certification

CMH-17
COMPOSITE MATERIALS HANDBOOK

- FAA guidance may reference industry publications, as shown below for AC 20-107B "Composite Aircraft Structure"

> (2) Existing references (e.g., The Composite Materials Handbook (CMH-17) Volumes 1 and 3, FAA Technical Report DOT/ FAA/AR-03/19), addressing composite qualification and equivalence and the building block approach, provide more detailed guidance regarding batch and test numbers and the appropriate statistical analysis up to laminate level. Changes at higher

- If no FAA guidance exists, applicants are encouraged to follow industry standards, like CMH-17

# Volume 5 Goals

CMH-17
COMPOSITE MATERIALS HANDBOOK

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

2. Document “best practices” for CMC design, processing, and operation.

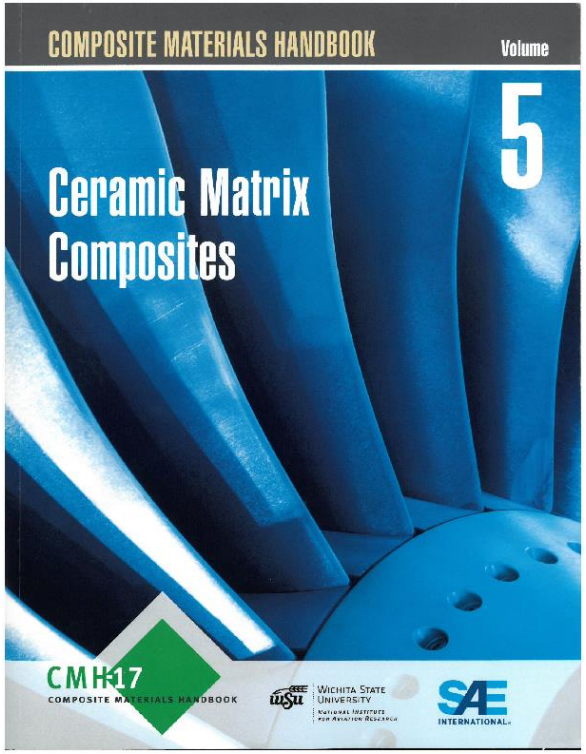
3. Document test and analysis methods that can be used to show compliance to civil and military aviation regulations.

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

# Status of CMH-17 Volume 5—Ceramic Matrix Composites

CMH-17
COMPOSITE MATERIALS HANDBOOK

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



# Updated Handbook is Available

CMH-17
COMPOSITE MATERIALS HANDBOOK

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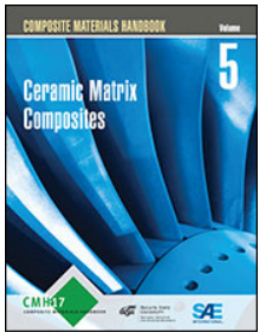
## Composite Materials Handbook Volume 5. Ceramic Matrix Composites

Book




The fifth volume of this six-volume compendium publishes technical guidance and properties on ceramic matrix composite material systems. The selected guidance on technical topics related to this class of composites includes material selection, processing, characterization, testing, data reduction, design, analysis, quality control, application, case histories, and lessons learned of typical ceramic matrix composite materials. Volume 5, which covers ceramic matrix composites, supersedes MIL-HDBK-17-5 of June 17, 2002.

The Composite Materials Handbook, referred to by industry groups as CMH-17, is an engineering reference tool that contains over 1,000 records of the latest test data for polymer matrix, metal matrix, ceramic matrix, and structural sandwich composites. CMH-17 provides information and guidance necessary to design and fabricate end items from composite materials. It includes properties of composite materials that meet specific data requirements as well as guidelines for design, analysis, material selection, manufacturing, quality control, and repair.

The primary purpose of the handbook is to standardize engineering methodologies related to testing, data reduction, and reporting of property data for current and emerging composite materials. It is used by engineers worldwide in designing and fabricating products made from composite materials.

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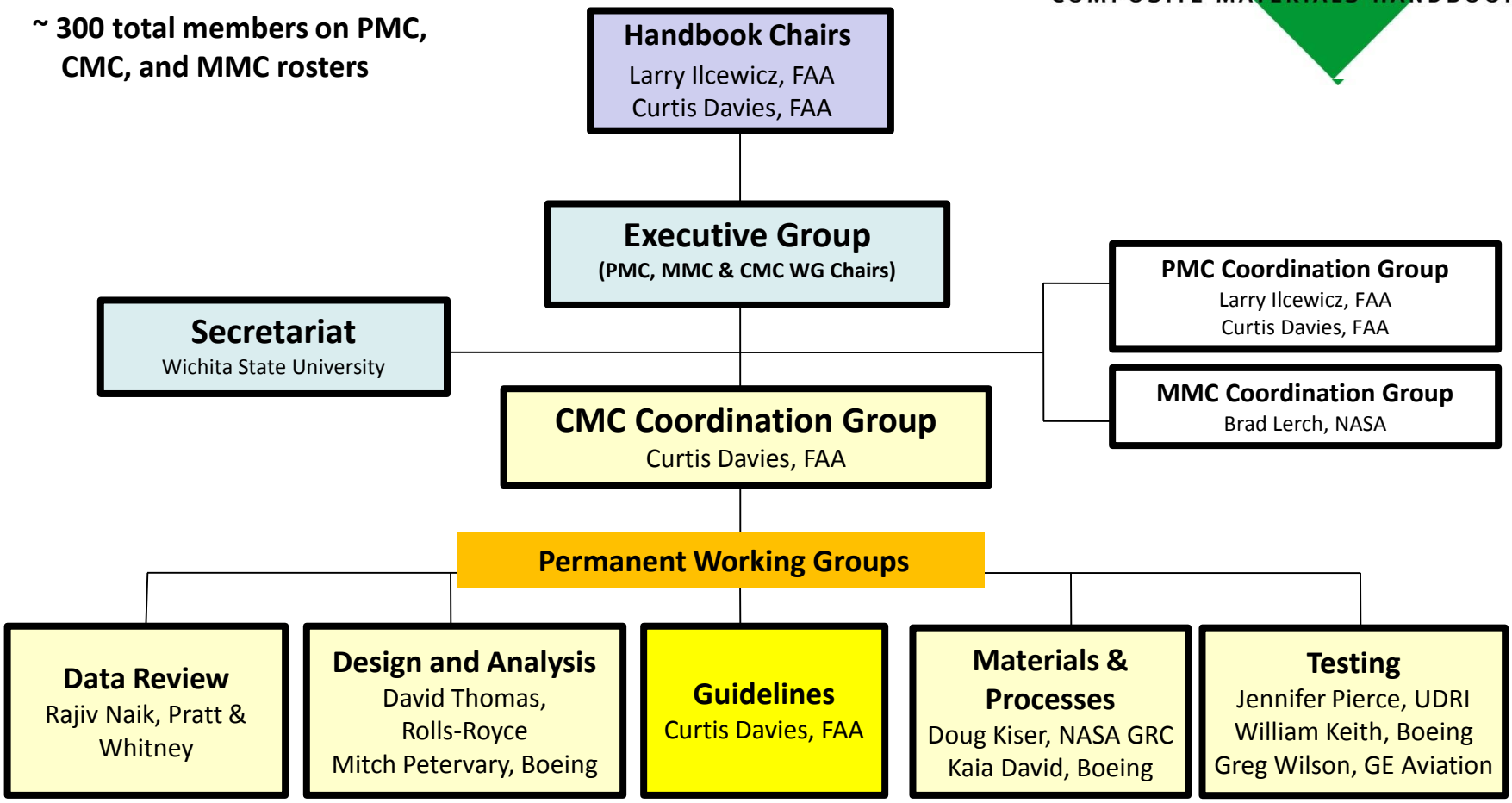
# CMH-17 CMC Coordination Group

CMH-17
COMPOSITE MATERIALS HANDBOOK

~ 300 total members on PMC, CMC, and MMC rosters



# Volume 5 Handbook Outline

CMH-17
COMPOSITE MATERIALS HANDBOOK

- **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**

# CMH-17 Working Group Approach

CMH-17
COMPOSITE MATERIALS HANDBOOK

**Provide standardized data and information by:**

- **Establishing and Maintaining Active CMC Working Groups (WG)**
  - Monthly WG Telecons – coordinate updating activities (Key)
  - Review and discuss progress, with a focus on specific subsections
  - Periodic review of content to identify gaps
  - Determine the agenda for upcoming meetings
  - Continue to recruit volunteers (increase group capability)
- **Periodically holding coordination meetings to discuss critical issues**
  - Annually with USACA (U.S. Advanced Ceramics Assoc.) in Cocoa Beach, FL
  - May hold additional meetings in conjunction with other CMC events such as the FAA CLEEN (Continuous Lower Energy, Emissions, and Noise Program) consortium

# Approach Used to Update Vol 5 Content

CMH-17
COMPOSITE MATERIALS HANDBOOK

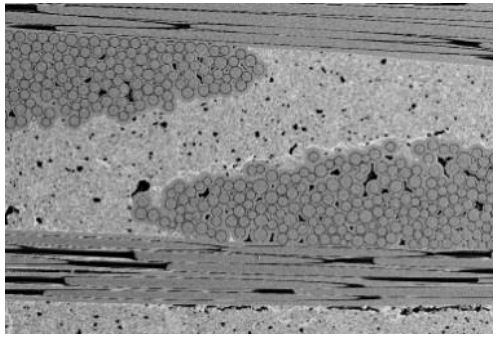
## Example: M&P WG Subsection Review Cycle

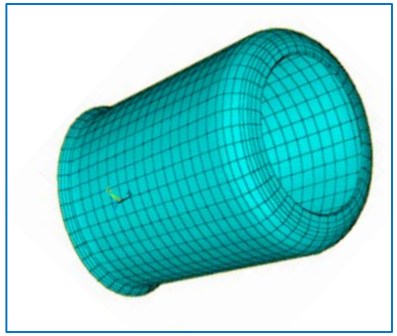
1. Subsection drafted / revised by SME (subject matter experts) in M&P WG
2. Next: Review within M&P WG and by other approved SME
3. Yellow Pages Review (by CMC "membership")
4. Final formatting / cleanup by Wichita State Univ. (CMH-17's Secretariat)
5. Ready for inclusion in revised CMH-17 Vol 5

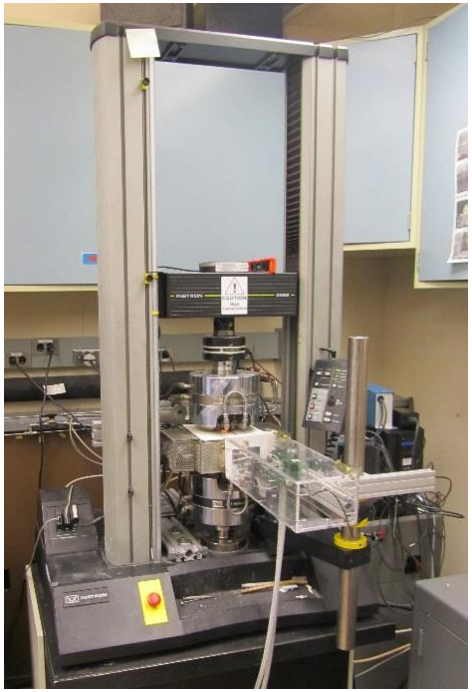
# CMC Working Group Activities

CMH-17
COMPOSITE MATERIALS HANDBOOK

- Materials and Processes
- Testing
- Data Review
- Design and Analysis







# Materials & Processes WG

CMH-17
COMPOSITE MATERIALS HANDBOOK

## Goals:

- 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 identify the essential information on composition, constituents/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 need to be coordinated with the Testing Working Group.

# New or Revised M&P Subsections

CMH-17
COMPOSITE MATERIALS HANDBOOK

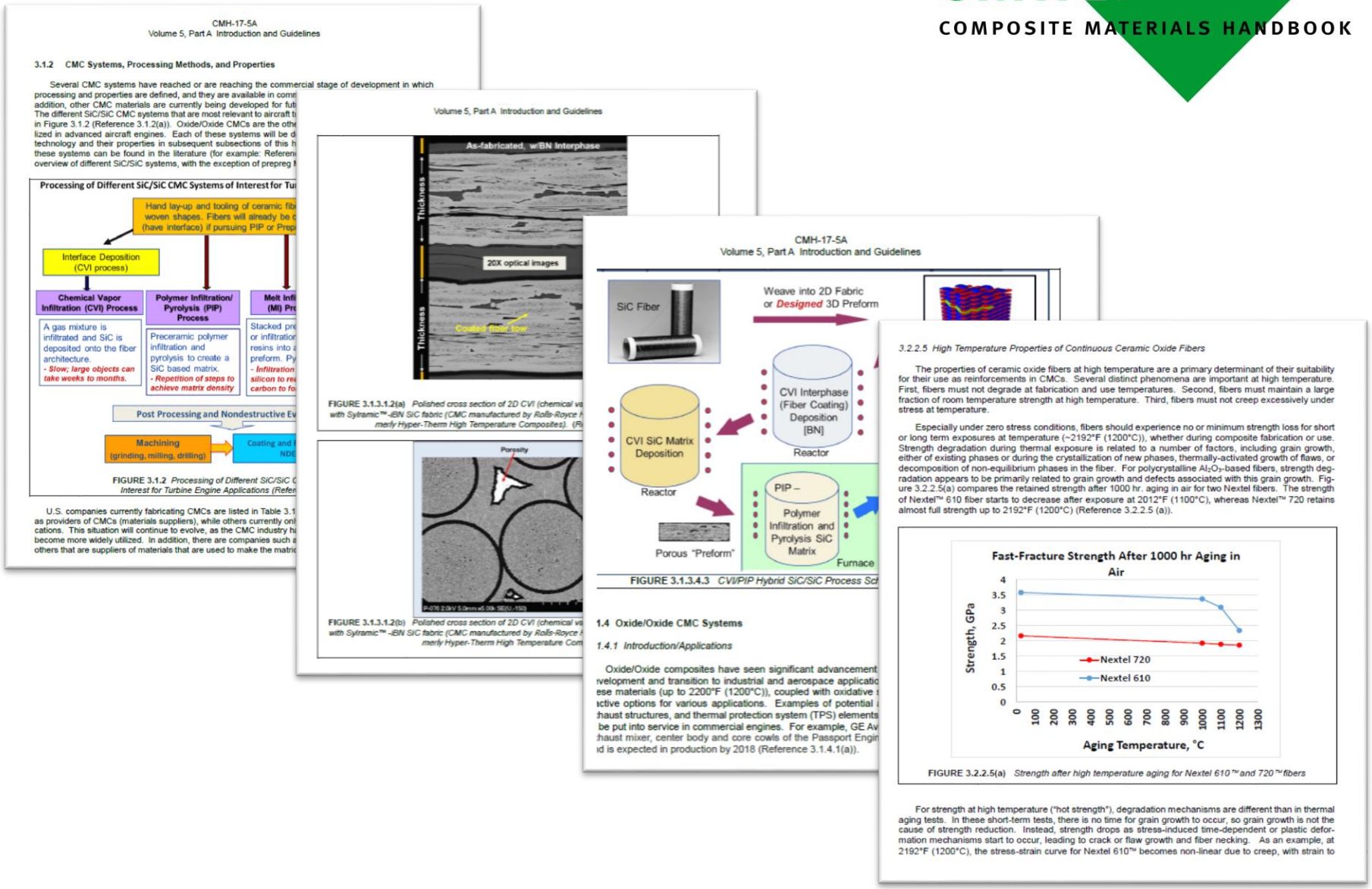
- CMC Systems:  Processing, Properties & Applications
- Fiber / Reinforcement Types and Technology
- Interphase / Interface Technology and Approaches
- Fabrication and Forming of Fiber Architectures
- External Protective Coatings for Non-Oxide CMCs
- External Protective Coatings for Oxide CMCs
- Characterization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

Chapter 3

- Quality Control of Production Materials and Processes Chapter 4
- Applications, Case Histories, and Lessons Learned Chapter 5

# New M&P Subsections - examples

CMH-17
COMPOSITE MATERIALS HANDBOOK



# Testing Working Group

CMH-17
COMPOSITE MATERIALS HANDBOOK

## Vision Statement:

- To be the primary and authoritative source for recommended/required methods for testing characterization of CMCs & their constituents

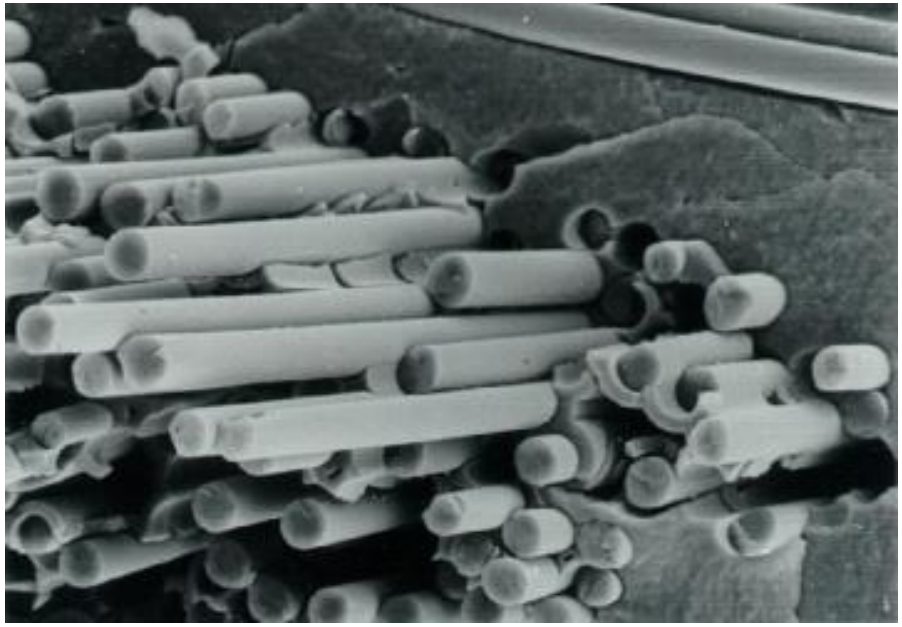
## Goals:

- 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 Subsections

CMH-17
COMPOSITE MATERIALS HANDBOOK

- Density
- Tensile Testing
- Shear Testing
- Notched Testing



# New Testing Subsections - examples

CMH-17
COMPOSITE MATERIALS HANDBOOK

## 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 f
matrix or other composite materials. Those referen

TABLE 13.6.2 Te

| Method | Title |
|---|---|
| ASTM C1275 | Monotonic Tensile Behav<br>ber-Reinforced Advanc<br>Solid Rectangular Cross<br>mens at Ambient Temper |
| ASTM C1359 | Monotonic Tensile Behav<br>ber-Reinforced Advanc<br>Solid Rectangular Cross<br>mens at Elevated Tempe |
| HSR-EPM –D-001-93 | Monotonic Tensile Testin<br>Intermetallic Matrix and<br>site Materials |
| ASTM D3039 | Tensile Properties of Pol<br>site Materials |



### 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 13.9.2 *Applicable test methods for CMC flexu*

| Method | Title | Materials | Temp |
|---|---|---|---|
| ASTM C1292 | Standard Test Method for Shear Strength of Continuous Fiber-Reinforced Advanced Ceramics at Ambient Temperatures1 | CMC | RT |
| ASTM C1425 | Interlaminar Shear Strength of 1-D and 2-D Continuous Fiber-Reinforced Advanced Ceramics at Elevated Temperatures | CMCs with oxide, SiC, glass (amorphous) matrices | ET |
| ASTM D3846 | Standard Test Method for In-Plane Shear Strength of Reinforced Plastics | Plastics | RT/ET |
| ASTM D2344 | Standard Test method for Short-Beam Strength of Polymer Matrix Composite Materials and Their Laminates | PMCs | RT/ET |
| ASTM D3518 | Standard Test Method for In-Plane Shear Response of a Polymer Matrix Composite Materials by Tensile Test of a ±45° Laminate | PMC | RT/ET |
| ASTM D5379 | Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method | PMCs | RT/ET |
| ASTM D7078 | Standard Test Method for Shear Properties of Composite Materials by V-Notched Rail Shear Method | PMCs | RT/ET |

## 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 13.11.1 - *Test Methods for Notched and Damaged Composite Laminates*

| Method | Title |
|---|---|
| ASTM D5766 | Open-Hole Tensile Strength of Polymer Matrix Composite Laminates |
| ASTM D6484 | Open-Hole Compressive Strength of Polymer Matrix Composite Laminates |
| ASTM D6742 | Filled-Hole Tension and Compression Testing of Polymer Matrix Composite Laminates |
| ASTM D7137 | Compressive Residual Strength Properties of Damaged Polymer Matrix Composite Plates |

### 13.11.2 Considerations for Notch Testing of CMCs

*13.11.2.1 Environments 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.

# Data Review Working Group

CMH-17
COMPOSITE MATERIALS HANDBOOK

## 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

# CMC Property Database

CMH-17
COMPOSITE MATERIALS HANDBOOK

*Currently not ITAR restricted*

| Composite Name | Composite Description | Producer |
|---|---|---|
| 9/99 EPM SiC/SiC | Sylramic™/BN-Si/MI SiC | **Ceramic Composite Products** |
| Enhanced SiC/SiC | CG Nicalon™/Carbon/CVI SiC | |
| Carbon/SiC | T300/Carbon/CVI SiC | |
| Hi-Nicalon/MI SiC | Hi-Nicalon™/BN/MI SiC | |
| AS-N720-1 | Nextel 720/alumino-silicate | **COI Ceramics** |
| Sylramic S-200 | CG Nicalon™/BN/PIP $Si_3N_4$-SiC | |

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

# New Data Review Subsections

CMH-17
COMPOSITE MATERIALS HANDBOOK

- Data Submission Requirements
- Calculation of Statistically Based Material Properties
- Statistical Methods for Material Equivalence and Acceptance

# New Data Review Subsections - examples

CMH-17
COMPOSITE MATERIALS HANDBOOK

### 17.3.2 Guide to computational procedures using the Single-Point method

The single-point method depicted in Figure 17.3.2 is used when all or portions of the data for multiple batches and environments do not satisfy one or m
least 3 batches and at least 2 environmental con
using the k-sample Anderson-Darling test, (iii) the
cepted for all environmental conditions, and (iv) e
satisfied. The single-point method also provides
tion for the calculation of basis values. The ana
17.3.2) is performed separately for each environm
data across environments. The CMH-17 STATS
associated with the single-point process.

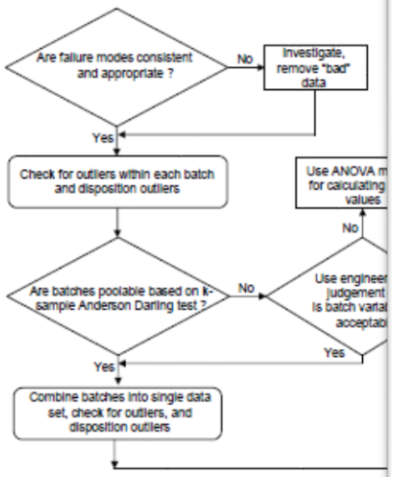



FIGURE 17.3.2 *Flowchart for sing*

CMH-17-5A
Volume 5, Part D Data Requirements and Data Sets

TABLE 18.1.3.2(a) *Summary Table format,* continued on next page.

X.X.X {Fiber} {Filament-Count}/{Interphase}/{Matrix} {Process Description}* ❶

| | | | |
|---|---|---|---|
| MATERIAL: | {Fiber} {Filament-Count}/{Interphase}/{Matrix} {Process Description} ❷ | | ❷ |
| FIBER: | {Commercial Name} {Continuous/Discontinuous} {Diameter} | INTERPHASE: | {Commercial Name} |
| MANUFACTURER: | {Fabrication Process Manufacturer} | MATRIX: | {Commercial Name} |
| PROCESS SEQUENCE: | {Process} | | ❹ |
| PROCESSING: | {Type of Process}: {Temperature}, {Duration}, {Pressure} | Source: | {Data source} |

*{Warning} ❸

| | | | |
|---|---|---|---|
| Date of fiber manufacture | MM/YY | Date of te | |
| Date of matrix manufacture | MM/YY | Date of d | |
| Date of composite manufacture | MM/YY | Date of a | |

LAMINA PROPERTY SUMMAR

| Temperature | (RT) | | {coldest to hottest} | | | |
|---|---|---|---|---|---|---|
| Environment | | | | | | |
| Fiber v/o | | | {lowest to highest} | | | |
| Tension, 1-axis | | | | | | |
| Tension, 2-axis | | | | | | |
| Tension, 3-axis | | | | | | |
| Compression, 1-axis | | | | | | |
| Compression, 2-axis | | | Classes of approval a each type test/direction/ condition/fiber volume | | | |
| Compression, 3-axis | | | | | | |
| Shear, 12-plane | | | | | | |
| Shear, 23-plane | | | | | | |
| Shear, 31-plane | | | | | | |
| {Additional type test/direction} | | | | | | |

Classes of data: F - Fully approved, I – Interim, S - Screening in ord
failure/Proportional Limit/0.2-offset-strength.

416

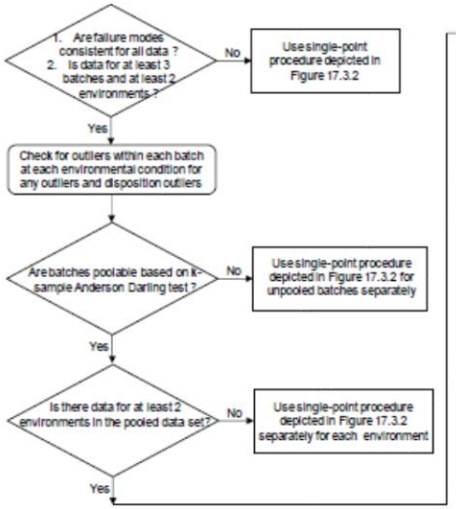



FIGURE 17.3.1 *Flowchart for pooled data basis value calculation procedure*

# Design and Analysis Working Group

CMH-17
COMPOSITE MATERIALS HANDBOOK

## 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

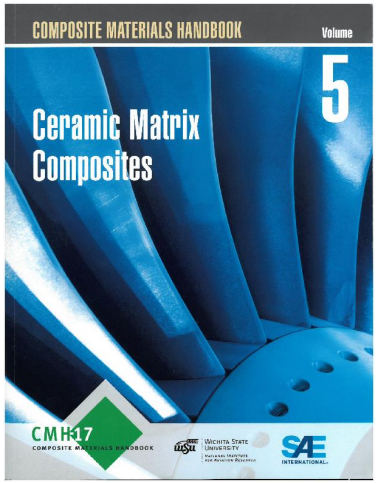
# New Design & Analysis Subsections

CMH-17
COMPOSITE MATERIALS HANDBOOK

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

# Summary / Plans for the Future

- The Composite Materials Handbook-17, Volume 5 on ceramic matrix composites has just been revised and released 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 w/ approximately 100 volunteers*
- Publication – through SAE International
- WGs will continue to update the content and are currently seeking volunteers
- A further update of Volume 5 by 2023 will be our new goal



# Moving Forward……

CMH-17
COMPOSITE MATERIALS HANDBOOK

**Individuals interested in contributing to the CMC working groups should please forward their contact information to**

**Rachael Andrulonis (rachael@cmh17.org)**

**and/or talk to any Working Group member.**

***Next Meeting to Discuss CMH-17 Vol 5:***
***Annual Meeting @ USACA – January 2018***
***Continue:***
***Monthly Teleconferences for Working Groups and Coordination***