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

Curtis Davies, Federal Aviation Administration, Atlantic City Intl. Airport, NJ
Cindy Ashforth, Federal Aviation Administration, Des Moines, WA
Rachael Andrulonis, Wichita State University, Wichita, KS
James Douglas Kiser, NASA Glenn Research Center, Cleveland, OH

45th Annual Conference on Composites, Materials, and Structures

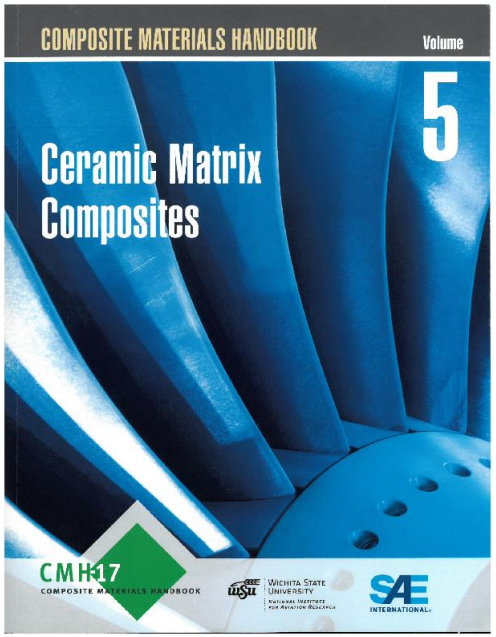
Cocoa Beach/Port Canaveral, FL

January 24 - 27, 2022

Overview

CMH-17
COMPOSITE MATERIALS HANDBOOK

- CMH-17 Organization
  - Mission and Vision
  - Structure
  - Objectives and Goals
  - Organization
  - History
  - Role in Civil Aircraft Certification
- Volume 5A (CMC) Handbook Content
  - Working Groups
- Summary



Composite Materials Handbook-17

CMH-17 Mission

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

CMH-17 Vision

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

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*
- Volume 4 Metal Matrix Composites
- **Volume 5 Ceramic Matrix Composites**
- Volume 6 Structural Sandwich Composites (PMCs)
- Volume 7 *Planned:* Additive Manufacturing (Non-Metallic)

PMC Handbooks are Significantly More Established

Composite Materials Handbook-17

CMH-17 Vol 5 Objectives

- The Composite Materials Handbook-17 (CMH-17) Vol 5 provides information and guidance necessary to design, fabricate, and use end items from ceramic matrix composites.
- Its primary purpose is the standardization of engineering methodologies (e.g. data collection, data development, design analysis, quality control, etc.) related to design, fabrication, maintenance, testing, data generation, and use of that data for current and emerging composite materials.
- In support of this objective, the Handbook includes CMC properties that meet specific data requirements and engineering methods that have been subject to rigorous review.
- The Handbook constitutes an overview of the field of CMCs materials technology and engineering; an area which is advancing and changing rapidly. As a result, the document is constantly being updated as sections are added or modified to reflect advances in the state-of-the-art.

Volume 5 Goals

CMH-17
COMPOSITE MATERIALS HANDBOOK

The handbook has three goals/purposes:

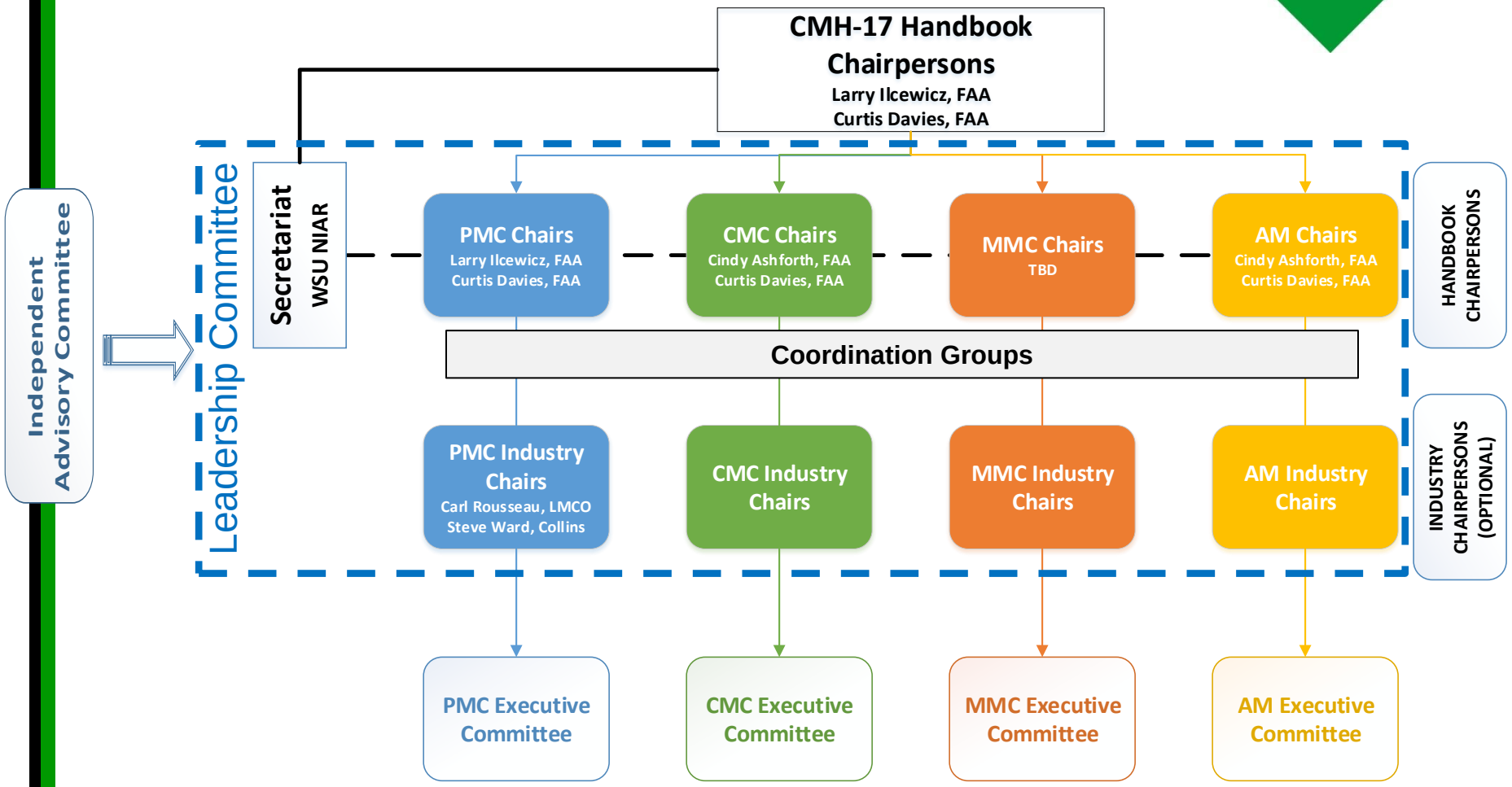
1. **Provide CMC material data**
   - Physical and mechanical properties
   - Tied to a single material specification AND a single process specification (published elsewhere, but publicly available)

2. **Describe how to generate CMC material data**
   - Material and process control
   - Document test methods
   - Test matrices
   - Statistical methods
   - Describe how to use material data

3. **Describe how to use CMC data**
   - Design Guide with proven methods / best practices
   - Analytical methods
   - Includes information on manufacturing and maintenance

The CMH-17 Organization

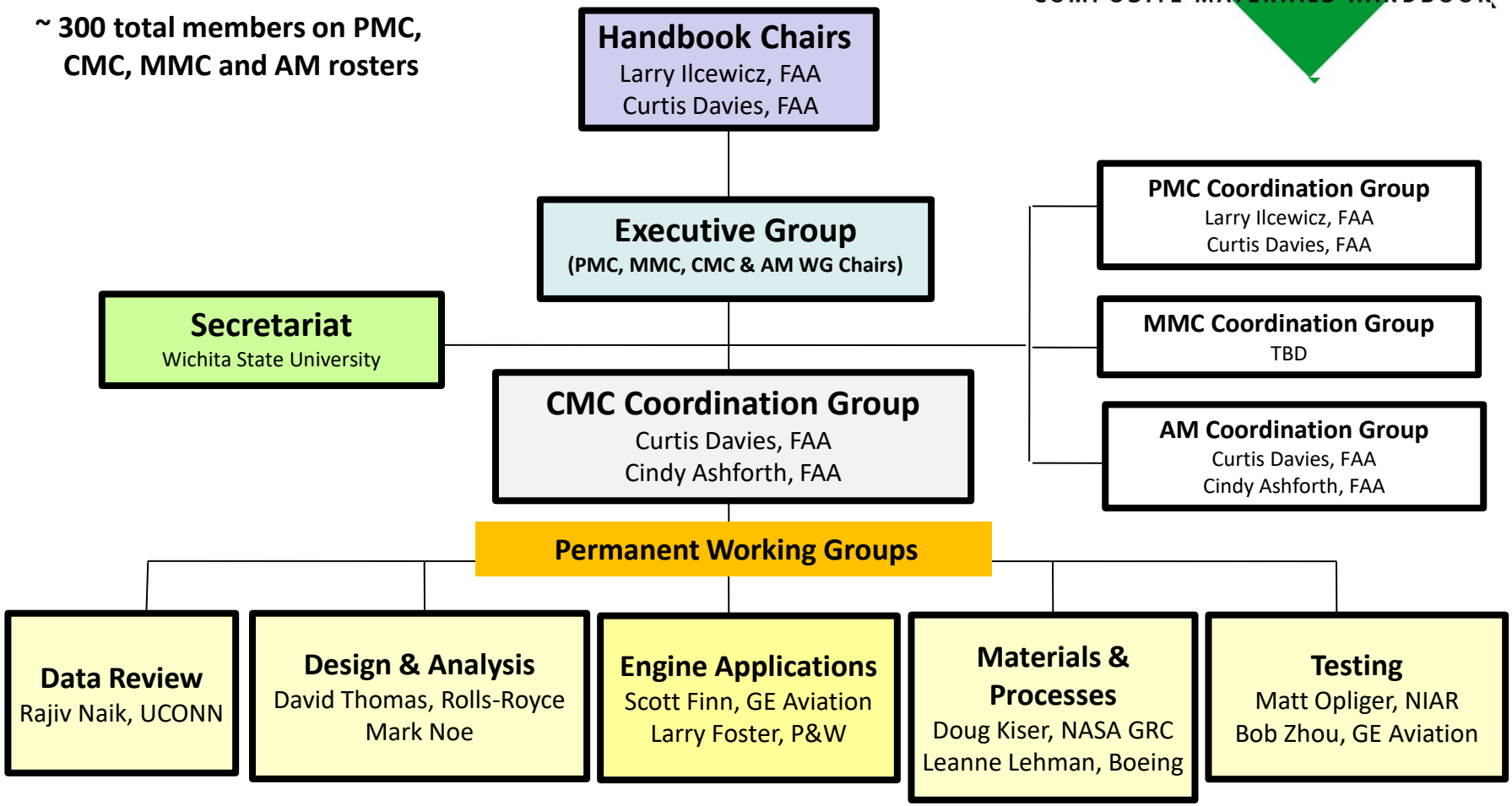
CMH-17
COMPOSITE MATERIALS HANDBOOK



- ***Independent Advisory Committee (still being formed):*** ***Will Provide Oversight/Direction for Handbook***
- ***Leadership Committee:*** ***Chairs from Different Coordination Groups and Secretariat w/PMC Focus***

CMH-17 CMC Coordination Group

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



- ***CMC Executive Committee:*** ***Chairs from Different Working Groups, FAA, and Secretariat***
- ***Engine Applications:*** ***New WG Addressing both PMCs and CMCs for Engine Applications***

Handbook History

2018 Release of Vol. 2H, AM Coordination Group Formed

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

Vol 5B: Planned Release 2022 / 2023

PMC: Polymer Matrix Composites
MMC: Metal Matrix Composites
CMC: Ceramic matrix Composites
AM: Additive Manufacturing

Certifying Composite Materials

CMH-17
COMPOSITE MATERIALS HANDBOOK

- **CMC components have entered service in commercial aircraft**
- **Composites are 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.***
- **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

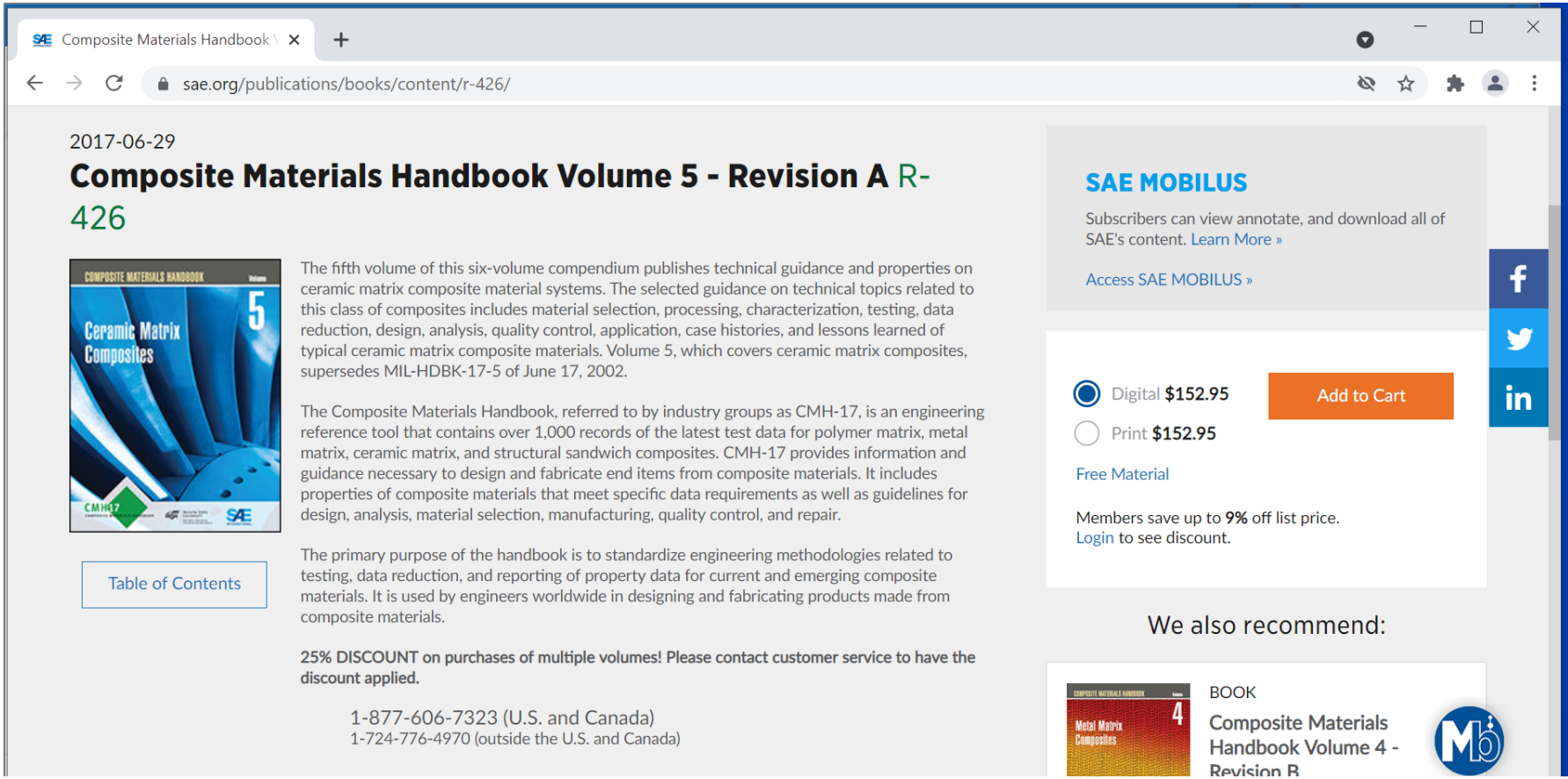
- **For CMCs: The FAA is currently defining means of compliance directly with applicant companies, although companies may adapt guidance in AC 20-107B and elsewhere.**
  - Applicants are encouraged to follow industry standards, like CMH-17

Federal Aviation Administration

Revision A Handbook is Available

CMH-17
COMPOSITE MATERIALS HANDBOOK

- **Hard copy or digital format**

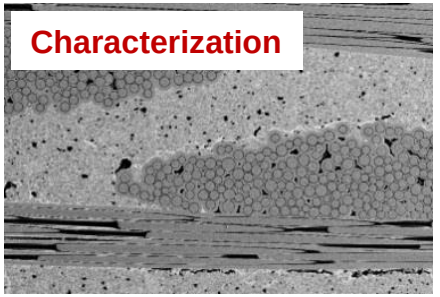


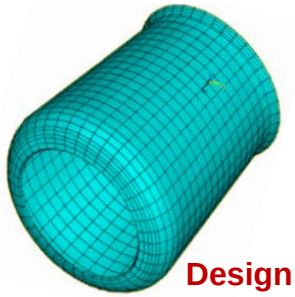
https://www.sae.org/publications/books/content/r-426/

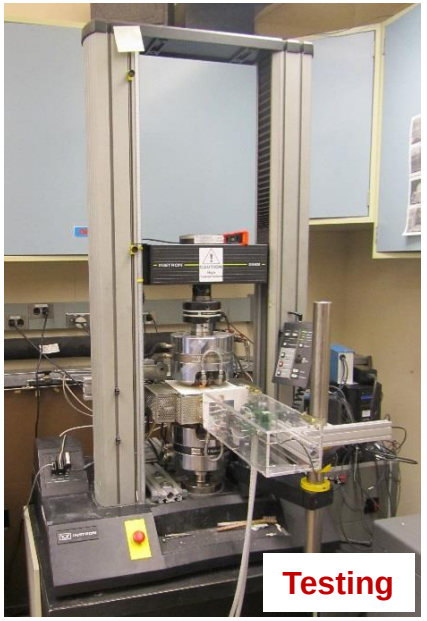
Volume 5 Handbook Outline

CMH-17
COMPOSITE MATERIALS HANDBOOK

- **Handbook currently 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**
  - ***Adding Engine Applications Content***







Groups primarily work independently to develop content for their portions of the handbook

Materials & Processes WG

CMH-17
COMPOSITE MATERIALS HANDBOOK

Vision:

To be the primary and authoritative source for information on the composition, fabrication, and characterization of CMC engineering materials and structures.

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.

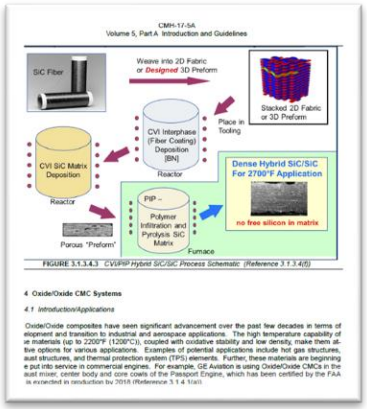
M&P Section Chapters are Informative and Could be Used by Instructors

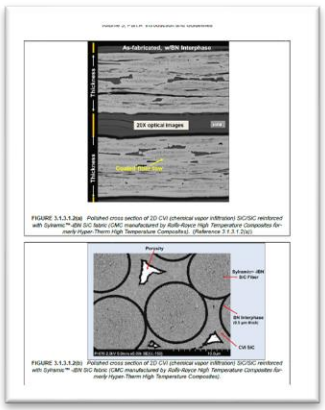
Materials & Processes Content

CMH-17
COMPOSITE MATERIALS HANDBOOK

Revision A (published)

- Introduction, History and Overview
- 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





Revision B (planned updates for 2022 / 2023)

- Introduction, History and Overview
- Hybrid SiC/SiC Composites (Slurry Cast MI SiC/SiC)
- Status of Commercial SiC Fiber Types for High-Temperature CMC Applications (GE fiber production in the US)
- Interphase/Interface Technology and Approaches (Multilayer fiber coating for Prepreg MI SiC/SiC)
- Fiber Architectures: Use of large oxide fiber tows for reducing oxide CMC fabrication costs
- External Protective Coatings (coatings for high temperature SiC/SiC *and* CMAS research)
- Characterization Methods (review existing content)
- NDE (add info. about NDE of shapes/components)
- Attachments (new section)
- Machining (review existing content—list vendors?)
- Quality Control of Production Materials and Processes

Need additional help in these areas

Design and Analysis Working Group

CMH-17
COMPOSITE MATERIALS HANDBOOK

Vision:

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

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

Design and Analysis Content

CMH-17
COMPOSITE MATERIALS HANDBOOK

Revision A (published)

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

Revision B (planned for 2022 / 2023)

- Design & Analysis Introduction
- Material Selection Considerations
- Manufacturing Process Selection
- Definition of Input Properties
- Verification by Analysis
- Verification by Test
- Maintainability and Supportability
- Substantiation Package for Certification

The highly proprietary nature of corporate design practices presents the greatest challenge to this Working Group

Testing Working Group

CMH-17
COMPOSITE MATERIALS HANDBOOK

Vision:

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

Testing WG coordinating with ASTM Committee C28 Advanced Ceramics
https://www.astm.org/COMMITTEE/C28.htm

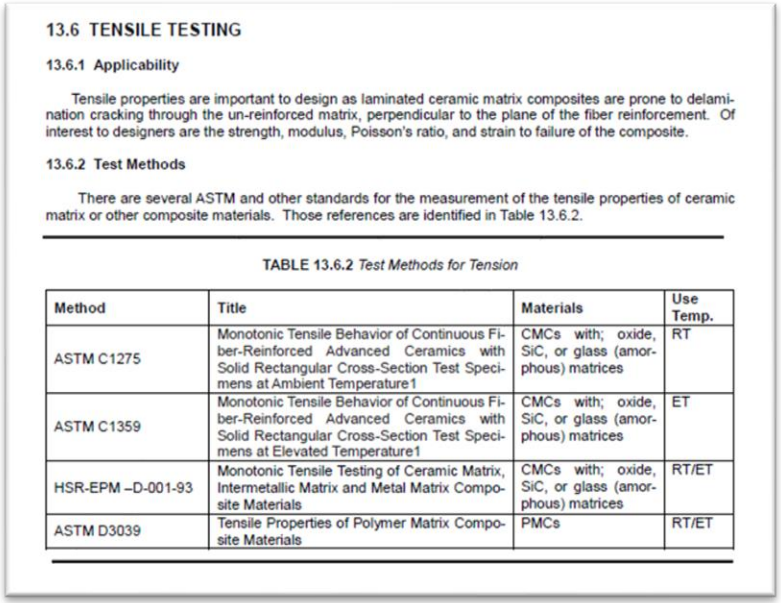
Testing WG content will be significantly increased in this update

Testing Content

CMH-17
COMPOSITE MATERIALS HANDBOOK

Revision A (published)

- Density
- Tensile Testing
- Shear Testing
- Notched Testing



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 the tensile properties of ceramic matrix or other composite materials. Those references are identified in Table 13.6.2.

TABLE 13.6.2 *Test Methods for Tension*

Method	Title	Materials	Use Temp.
ASTM C1275	Monotonic Tensile Behavior of Continuous Fiber-Reinforced Advanced Ceramics with Solid Rectangular Cross-Section Test Specimens at Ambient Temperature1	CMCs with; oxide, SiC, or glass (amorphous) matrices	RT
ASTM C1359	Monotonic Tensile Behavior of Continuous Fiber-Reinforced Advanced Ceramics with Solid Rectangular Cross-Section Test Specimens at Elevated Temperature1	CMCs with; oxide, SiC, or glass (amorphous) matrices	ET
HSR-EPM –D-001-93	Monotonic Tensile Testing of Ceramic Matrix, Intermetallic Matrix and Metal Matrix Composite Materials	CMCs with; oxide, SiC, or glass (amorphous) matrices	RT/ET
ASTM D3039	Tensile Properties of Polymer Matrix Composite Materials	PMCs	RT/ET

Revision B (planned)

- **Evaluation of Reinforcements**
  - **Mechanical Properties**
- **Evaluation of Matrix Materials**
  - **Mechanical Properties**
  - **Thermal Properties**
- **Evaluation of Composites**
  - **Density**
  - **Fiber Volume Fraction**
  - **Coefficient of Thermal Expansion (CTE)**
  - **Thermal Conductivity**
  - **Specific Heat**
  - **Compression**
  - **Flexure**
  - **Interlaminar Tension**
  - **Interlaminar Fracture Toughness**
  - **Creep Testing**
  - **Fatigue Testing**
  - **Wear Testing**
  - **Bearing Testing**
  - **Biaxial Testing**

Data Review Working Group

CMH-17
COMPOSITE MATERIALS HANDBOOK

Vision:

To be the primary and authoritative source for statistically validated data on ceramic matrix composite materials.

Goals:

- 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.

Handbook currently contains some data sets for older CMC systems

Data Review Content

CMH-17
COMPOSITE MATERIALS HANDBOOK

Revision A (published)

- CMC Screening data including:
  - 9/99 EPM SiC/SiC
  - Enhanced SiC/SiC
  - Carbon/SiC
  - Hi-Nicalon™/MI SiC
  - AS-N720-1
  - Sylramic™ S-200

Not considered "fully approved" data

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

Revision B (planned for 2023)

- New CMC data
  - Oxide/Oxide Axiom 7800 5HS (B-basis allowables and specs)
  - Others?

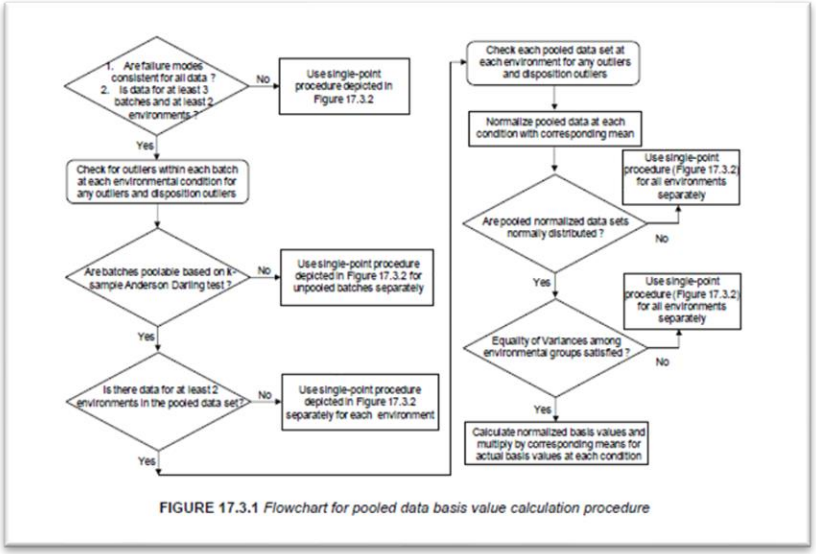


FIGURE 17.3.1 *Flowchart for pooled data basis value calculation procedure*

Engine Applications WG*

CMH-17
COMPOSITE MATERIALS HANDBOOK

Vision:

To be the primary and authoritative source for information on the composition, fabrication, and characterization of PMC and CMC engineering materials and structures for aircraft engine applications.

Goals:

Improve the usefulness of CMH-17 to the aircraft engine technical community by:

1. Developing new CMH-17 content specific to aircraft engines for both rotating and stationary parts (excluding nacelles and pylons);
2. Summarizing how existing CMH-17 content applies to typical design, materials, manufacturing, maintenance, and certification activities for aircraft engine composite parts;
3. Documenting industry best practices for the use of composites in aircraft engines; and
4. Ensuring consistent content across PMC and CMC volumes.

**New group formed in early 2021*

Engine Applications Content

CMH-17
COMPOSITE MATERIALS HANDBOOK

Volume 3, Chapter 20 Outline (Draft)

1. Introduction
2. Typical Materials and Manufacturing Processes
3. Specialized Testing
4. Design Considerations
5. Analysis
6. Defects and Damage Tolerance
7. Fatigue and Vibration

Linkage to Volume 5B will be determined. The content will address both PMC and CMC materials and applications.

CMH-17 Working Group Approach

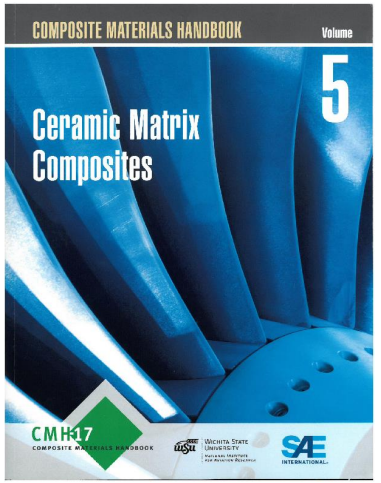
CMH-17
COMPOSITE MATERIALS HANDBOOK

Provide standardized data and information by:

- **Establishing and Maintaining Active CMC Working Groups (WG)**
  - Monthly WG Telecons: coordinate updating activities (Key)
  - Use of Confluence site for sharing documents
  - Continue to recruit volunteers (increase group capability)
  - Overall tracking sheet for reporting WG status/progress (Confluence)
- **Periodically holding coordination meetings to discuss critical issues**
  - Annually with USACA (U.S. Advanced Ceramics Assoc.) in Cocoa Beach, FL
  - Holding periodic virtual conferences to allow the Working Groups to share content with each other and improve communication

Summary

- The Composite Materials Handbook-17, Volume 5 on ceramic matrix composites is available* as a useful guide for CMCs:
  - CMC Materials / Processing
  - Design / Analysis Guidelines
  - Testing Procedures
  - Data Analysis and Acceptance
- It continues to be developed w/support from volunteer technical experts from Industry, Government, and Academia
- Release of Volume 5B by 2022/2023 is our goal



* Publication – through SAE International

For more information…..

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COMPOSITE MATERIALS HANDBOOK

Individuals interested in contributing to the CMC working groups should please forward their contact information to the CMH-17 Secretariat

(info@cmh17.org)

and/or talk to any Working Group member.