CMH-17
COMPOSITE MATERIALS HANDBOOK

CMH-17 Volume 5
Ceramic Matrix Composites

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ASME Turbo Expo

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Overview

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

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.

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

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 (Initial Release)

Volume 5 Goals

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

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

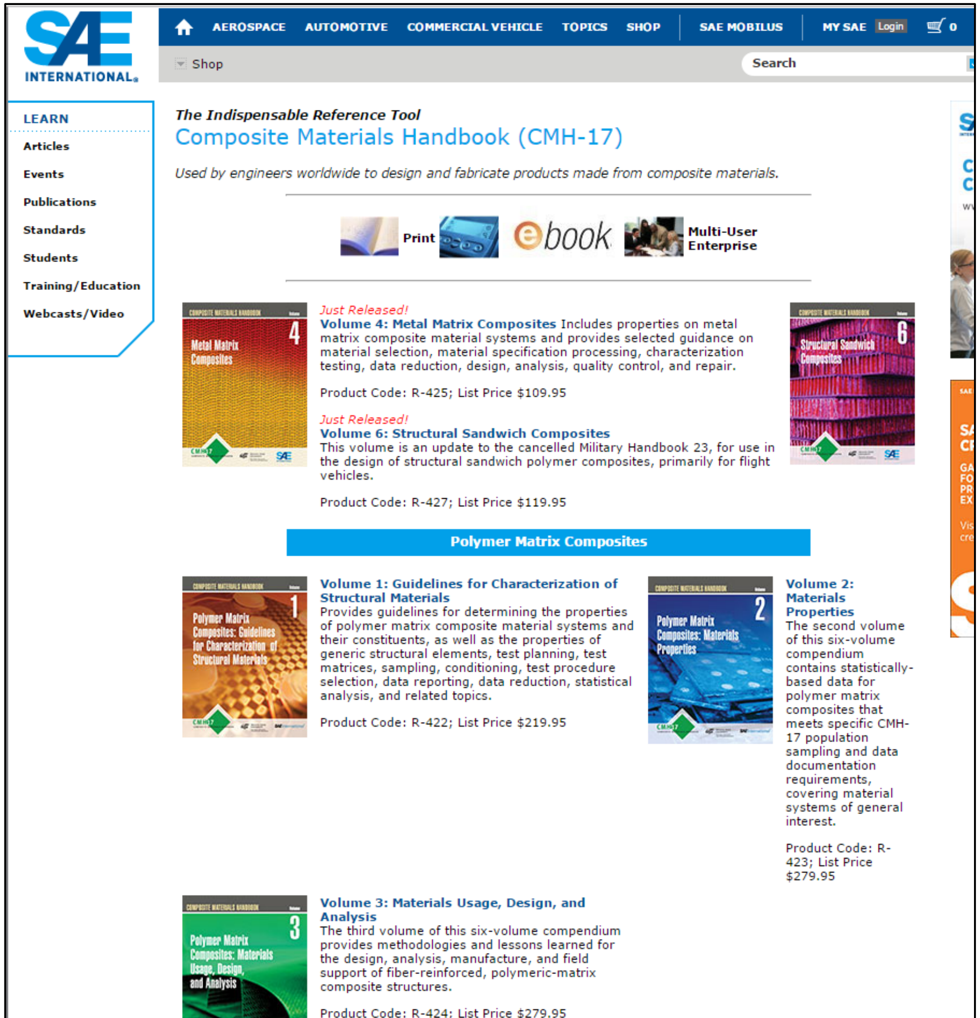
1959 MIL-HDBK-17 Plastics for Air Vehicles

1943 ANC Bulletin 17 Plastics for Aircraft

Last CMC handbook issued ~15 years ago

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

SAE International



http://store.sae.org/cmh-17/

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

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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
Federal Aviation Administration

What is the Importance of CMH-17 Volume 5—Ceramic Matrix Composites? *(continued)*

CMH-17 COMPOSITE MATERIALS HANDBOOK

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

CMH-17 COMPOSITE MATERIALS HANDBOOK

~ 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

PMC Coordination Group
Larry Ilcewicz, FAA
Curtis Davies, FAA

MMC Coordination Group
Brad Lerch, NASA

CMC Coordination Group
Curtis Davies, FAA

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

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COMPOSITE MATERIALS HANDBOOK

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

Materials & Processes WG

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

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- 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 Sections - examples

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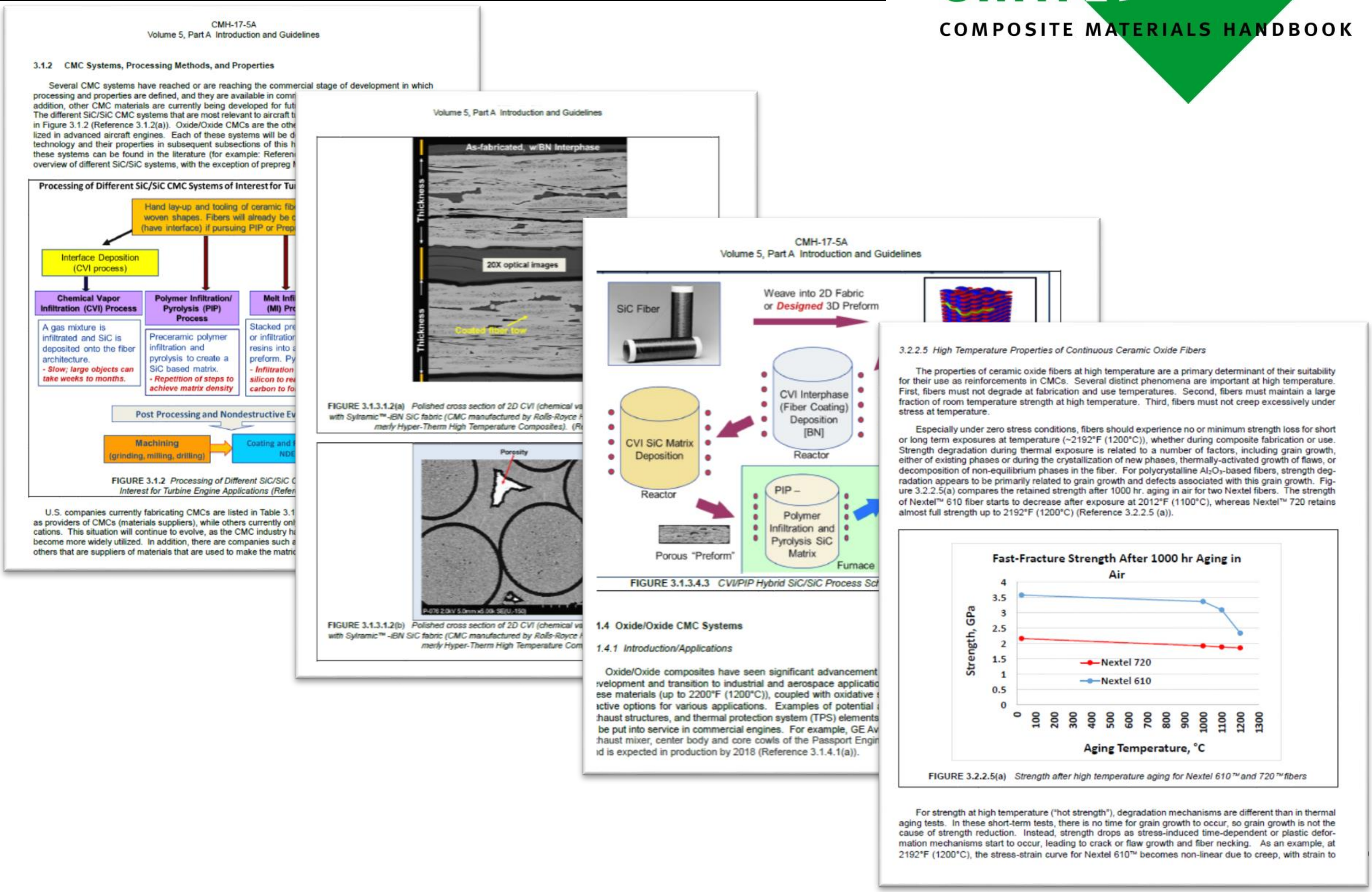

Design and Analysis Working Group

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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

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- Density
- Tensile Testing
- Shear Testing
- Notched Testing

New Testing Sections - examples

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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 referenc

TABLE 13.6.2 *Tes*

Method	Title
ASTM C1275	Monotonic Tensile Behavi ber-Reinforced Advance Solid Rectangular Cross- mens at Ambient Temper
ASTM C1359	Monotonic Tensile Behavi ber-Reinforced Advance Solid Rectangular Cross- mens at Elevated Temper
HSR-EPM –D-001-93	Monotonic Tensile Testin Intermetallic Matrix and M site Materials
ASTM D3039	Tensile Properties of Poly 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 flexur*

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

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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

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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	**Ceramic Composite Products**
Carbon/SiC	T300/Carbon/CVI SiC	**Ceramic Composite Products**
Hi-Nicalon/MI SiC	Hi-Nicalon™/BN/MI SiC	**Ceramic Composite Products**
AS-N720-1	Nextel 720/alumino-silicate	**COI Ceramics**
Sylramic S-200	CG Nicalon™/BN/PIP Si_3N_4-SiC	**COI Ceramics**

- 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

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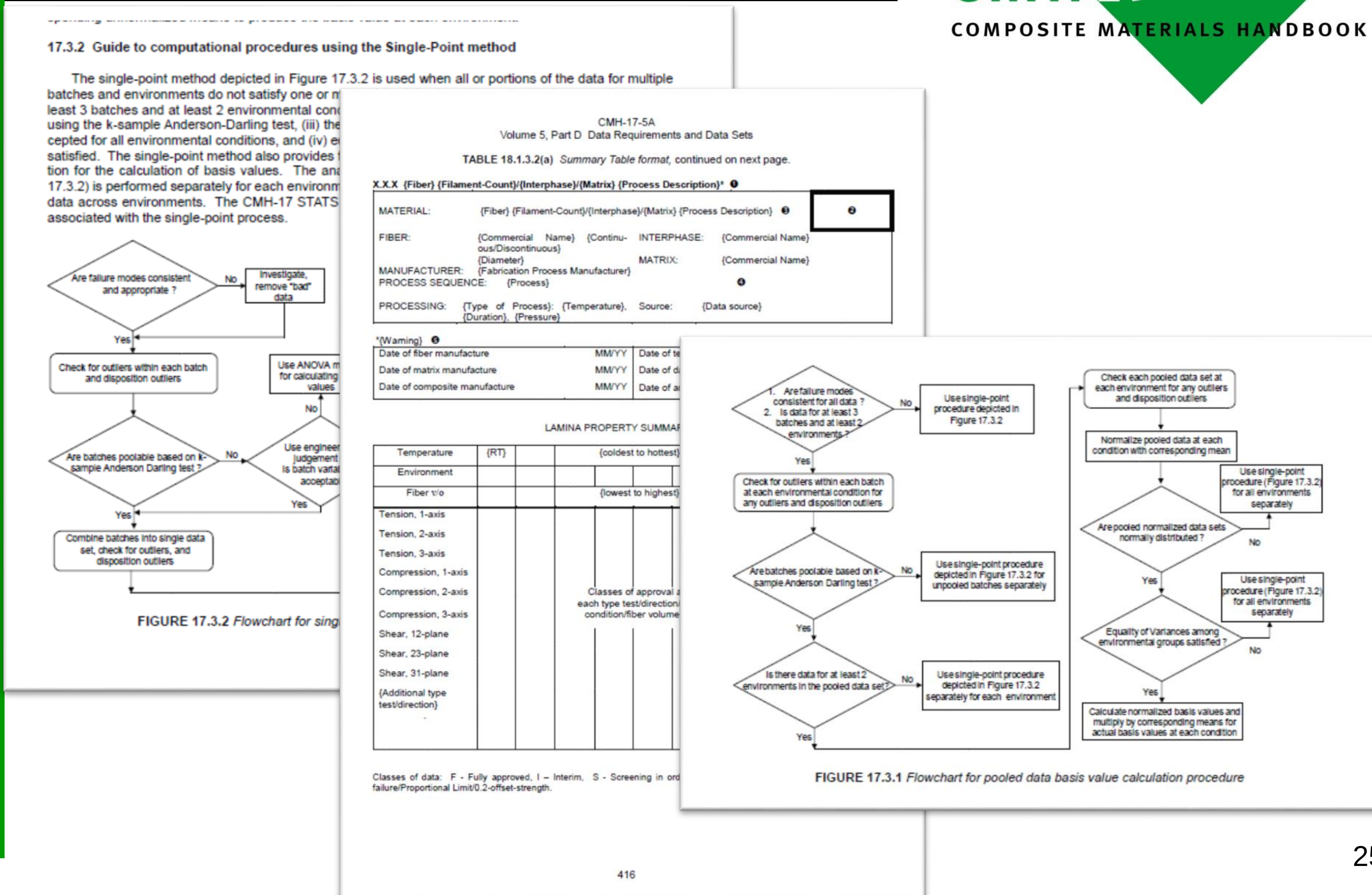

Summary

CMH-17
COMPOSITE MATERIALS HANDBOOK

- 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**

Summary

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