

# Polymer Matrix Composites: Guidelines for Characterization of Structural Materials

**CMH-17**

COMPOSITE MATERIALS HANDBOOK



WICHITA STATE  
UNIVERSITY



**NOT MEASUREMENT  
SENSITIVE**

CMH-17-1H  
Volume 1 of 6  
**AUGUST 2022**

Superseding  
CMH-17-1G  
**MARCH 2012**

# **COMPOSITE MATERIALS HANDBOOK**

## **POLYMER MATRIX COMPOSITES GUIDELINES FOR CHARACTERIZATION OF STRUCTURAL MATERIALS**

**VOLUME 1. Revision H**



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The underlying data from the work conducted under Cooperative Agreement Number 12-C-AM-WISU is publicly available and accessible at from the Defense Logistics Agency (DLA) Document Services, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

## FOREWORD

The Composite Materials Handbook, CMH-17, provides information and guidance necessary to design and fabricate structural components from composite materials. Its primary purposes are a) the standardization of engineering data development methodologies related to testing, data reduction, and data reporting of property data for current and emerging composite materials, b) guidance on material and process specifications and procedures for utilization of the material data presented in the handbook, and c) methodologies for the design, analysis, certification, manufacture, and field support of composite structures. In support of these objectives, the handbook includes composite materials properties that meet specific data requirements. The handbook therefore constitutes an overview of the field of composites technology and engineering, an area that is advancing and changing to support new applications. As a result, the document will be continually revised as sections are added or modified to reflect advances in best industry practices.

### CMH-17 Mission

The Composite Materials Handbook 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.

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

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- To periodically meet with experts from the field to discuss critical technical issues for composite structural applications, with an emphasis on increasing overall product efficiency, quality, and safety
- To provide comprehensive, practical engineering guidance that has proven reliable for the design, fabrication, characterization, test, and maintenance of composite materials and structures
- To provide reliable data, linked to control of processes and raw materials, thereby being a comprehensive source of material property basis values and design information that can be shared within the industry
- To provide a resource for composite material and structure education with examples, applications and references to supporting engineering work
- To establish guidelines for use of information in the handbook, identifying the limitations of the data and methods
- To provide guidance on references to proven standards and engineering practices
- To provide for periodic updates to maintain the all-inclusive nature of the information
- To provide information in formats best suited for user needs
- To serve the needs of the international composites community through meetings and dialog between member industries, which use teamwork and the diverse member engineering skills to provide information for the handbook

**Notes**

1. Every effort has been made to reflect the latest information on polymer (organic), metal, and ceramic composites. The handbook is continually reviewed and revised to ensure it is complete and current.
2. CMH-17 provides guidelines and material properties for polymer (organic), metal, and ceramic matrix composite materials. The first three volumes of this handbook currently focus on, but are not limited to, polymeric composites intended for aircraft and aerospace vehicles. Metal matrix composites (MMC), ceramic matrix composites (CMC), and sandwich composites are covered in Volumes 4, 5, and 6, respectively. The organization is also developing a new Volume 7 for non-metallic additive manufacturing.
3. The information contained in this handbook was obtained from materials producers, industry companies and experts, reports on government-sponsored research, the open literature, and by contract with research laboratories and those who participate in the CMH-17 coordination activity. The information in this handbook has undergone vigorous technical review and was subject to membership vote.
4. Beneficial comments (recommendations, additions, and deletions) and any pertinent data which may be of use in improving this document should be addressed to: CMH-17 Secretariat, Wichita State University, 1845 Fairmount, Wichita, KS 67260, by letter or email, [info@cmh17.org](mailto:info@cmh17.org).

**ACKNOWLEDGEMENT**

Committee members from government, industry, and academia develop, coordinate, and review all the information provided in this handbook. The time and effort of the members and the support of their respective departments, companies, and universities make it possible to ensure the handbook reflects completeness, accuracy, and industry best practices.

Support necessary for the development and maintenance of the Composite Materials Handbook (CMH-17) is provided by the Handbook Secretariat, Wichita State University. The primary source of funding for the current Secretariat contract is the Federal Aviation Administration.

## SUMMARY OF CHANGES

| Chapter  | Section   | Title   | Change type / Proceedings  |
|----------|-----------|---|--|
|          | Cover     | Cover   | CMH-17 Leadership Committee  |
|          | Foreword  | Foreword  | CMH-17 Leadership Committee  |
| <b>1</b> |           | <b><u>Objectives</u></b>  |  |
|          | 1.4.1     | Roadmaps for use of Volumes 1 - 3                                 | Revision / Virtual (7/20)  |
|          | 1.7.1.2   | Laminae and laminates   | Revision / Salt Lake City (3/15)   |
|          | 1.8       | Definitions   | Revision and New / Salt Lake City (3/15, 3/17), Charleston (7/18), Salt Lake City (3/19)   |
| <b>2</b> |           | <b><u>Guidelines for Property Testing of Composites</u></b>       |  |
|          | ALL       | Complete chapter revision   | Revision / Salt Lake City (2/17), Charleston (7/18), Salt Lake City (3/19), virtual (7/20) |
| <b>3</b> |           | <b><u>Evaluation of Reinforcement Fibers</u></b>                  |  |
|          | ALL       | Complete chapter revision   | Revision / Salt Lake City (3/19), Wichita (10/19)  |
| <b>4</b> |           | <b><u>Matrix Characterization</u></b>                             |  |
|          | ALL       | Complete chapter revision   | Revision / Salt Lake City (3/19), Virtual (7/20)   |
| <b>5</b> |           | <b><u>Prepreg Material Characterization</u></b>                   |  |
|          | Chapter 5 | Complete chapter revision   | Revision / Wichita (11/17), Salt Lake City (3/19)  |
| <b>6</b> |           | <b><u>Lamina, Laminate, and Special Form Characterization</u></b> |  |
|          | 6.2       | Specimen Preparation  | Revision / Virtual (7/20)  |
|          | 6.3       | Conditioning and Environmental Exposure                           | Revision / Wichita (10/19), Virtual (7/20)   |
|          | 6.4       | Instrumentation and Calibration                                   | Revision / Virtual (7/20)  |
|          | 6.5       | Testing Environments  | Revision / Virtual (7/20)  |
|          | 6.6       | Thermal/Physical Property Tests                                   | Revision / Wichita (11/17 and 10/19), Virtual (7/20)                                       |
|          | 6.8       | Static Uniaxial Mechanical Property Tests                         | Revision / Virtual (7/20)  |
|          | 6.8.6     | Fracture Toughness  | revision / Virtual (7/20)  |
|          | 6.11      | Viscoelastic Properties Tests                                     | Revision / Virtual (7/20)  |

| <b>Chapter</b> | <b>Section</b> | <b>Title</b>   | <b>Change type / Proceedings</b>                 |
|----------------|----------------|--|--|
| <b>7</b>       |                | <b><u>Structural Element Characterization</u></b>  |  |
|                | ALL            | Complete chapter revision  | Revision / Salt Lake City (3/19)                 |
|                | 7.6            | Bonded joint tests   | Revision / Virtual (7/20)                        |
|                | 7.8            | High Load Rate and Dynamic Testing   | New / Virtual (7/20)                             |
| <b>8</b>       |                | <b><u>Statistical Methods</u></b>  |  |
|                | 8              | References and examples to CMH-17 STATS updated throughout   |  |
|                | 8.3.7          | Calculation of basis values for structured data using regression analysis  | Revision / Salt Lake City (3/19), Virtual (7/20) |
|                | 8.4            | Statistical Methods  | Revision / Virtual (7/20)                        |
|                | 8.4.1          | Methods to set material specification limits or determine equivalency between an existing database and a new dataset for the same material | Revision / Salt Lake City (3/19)                 |
|                | 8.4.2.2        | Test method induced variability in comparing two groups  | New / Virtual (3/21)                             |
|                | 8.4.7          | General linear statistical models  | Revision / Salt Lake City (3/19)                 |

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**17 JUNE 2012**

# **COMPOSITE MATERIALS HANDBOOK**

## **POLYMER MATRIX COMPOSITES: MATERIALS PROPERTIES**

**VOLUME 2. Rev. H/Part A**



**CMH-17**  
**COMPOSITE MATERIALS HANDBOOK**

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**SUMMARY OF CHANGES**

| <b>Chapter</b> | <b>Section<br/>[old section #]</b>   | <b>Title</b>   | <b>Change type</b>                                  |
|----------------|--------------------------------------|--|---|
| <b>1</b>       |                                      | <b><u>General Information</u></b>  |   |
|                | 1.7.1.2                              | Laminae and laminates  | Revision/Salt Lake City (3/2015)                    |
|                | 1.8                                  | Definitions  | Revision and new/Salt Lake City (3/2015 and 3/2017) |
|                | 1.10<br>[Volume 1,<br>Section 2.4]   | Data Reduction and Documentation   | Reorganization/Wichita (12/2013)                    |
|                | 1.11<br>[Volume 1,<br>Section 2.5]   | Material Testing for Submission of Data to CMH-17                                | Reorganization/Wichita (12/2013)                    |
|                | 1.12<br>[Volume 1,<br>Section 2.3.7] | Data Substantiation for Use of Basis Values from CMH-17 or Other Large Databases | Reorganization/Wichita (12/2013)                    |
| <b>2</b>       |                                      | <b><u>Carbon Fiber Properties</u></b>  |   |
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|                | 2.2.1.4                              | IM7 12k/8552 Unidirectional Tape   | New/Supplemental YPs (3/2015)                       |
|                | 2.2.1.5                              | T650 6k/5320 Unidirectional Tape   | New/Wichita (10/2015)                               |
|                | 2.2.1.6                              | IM7 12k/MTM45-1 Unidirectional Tape  | New/Salt Lake City (3/2015)                         |
|                | 2.2.1.7                              | HTS40 12k/MTM45-1 Unidirectional Tape  | New/Salt Lake City (3/2015)                         |
|                | 2.2.1.8                              | AS4 12k/MTM45-1 Unidirectional Tape  | New/Salt Lake City (3/2015)                         |
|                | 2.2.1.9                              | IM7 12k/EP2202 Unidirectional Tape   | New/Salt Lake City (3/2017)                         |
|                | 2.2.1.10                             | IM7 GP 12k/BT250E-6 Unidirectional Tape  | New/St. Paul (8/2016)                               |
|                | 2.2.2.5                              | AS4 3k/8552 Plain Weave Fabric   | New/Wichita (12/2013)                               |
|                | 2.2.2.6                              | HTS40 E13 3k/MTM45-1 Plain Weave Fabric  | New/Miami (8/2014)                                  |
|                | 2.2.2.7                              | T650 3k/5320-1 Plain Weave Fabric  | New/Supplemental YPs (3/2015)                       |
|                | 2.2.2.8                              | HTS40/TC250 Plain Weave Fabric   | New/Salt Lake City (3/2015)                         |
|                | 2.2.2.9                              | AS4C 3k/BT250-E Plain Weave Fabric   | New/St. Paul (8/2016)                               |
|                | 2.2.2.10                             | T650/EP2202 Plain Weave Fabric   | New/Salt Lake City (3/2017)                         |

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# Polymer Matrix Composites: Materials Properties

CMH-17

COMPOSITE MATERIALS HANDBOOK



WICHITA STATE  
UNIVERSITY



**NOT MEASUREMENT  
SENSITIVE**

CMH-17-2H  
Volume 2 of 6  
**FEBRUARY 2018**

SUPERSEDING  
CMH-17-2G  
Volume 2 of 6  
**17 JUNE 2012**

# **COMPOSITE MATERIALS HANDBOOK**

## **POLYMER MATRIX COMPOSITES: MATERIALS PROPERTIES**

**VOLUME 2. Rev. H/Part B**



**CMH-17**  
**COMPOSITE MATERIALS HANDBOOK**

**ISBN-Print 978-0-7680-9481-7**

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## FOREWORD

The Composite Materials Handbook, CMH-17, provides information and guidance necessary to design and fabricate structural components from composite materials. Its primary purposes are a) the standardization of engineering data development methodologies related to testing, data reduction, and data reporting of property data for current and emerging composite materials, b) guidance on material and process specifications and procedures for utilization of the material data presented in the handbook, and c) methodologies for the design, analysis, certification, manufacture, and field support of composite structures. In support of these objectives, the handbook includes composite materials properties that meet specific data requirements. The handbook therefore constitutes an overview of the field of composites technology and engineering, an area that is advancing and changing rapidly. As a result, the document will be continually revised as sections are added or modified to reflect advances in the state of the art.

### CMH-17 Mission

The Composite Materials Handbook 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.

### Goals and Objectives to Support the CMH-17 Mission

- To periodically meet with experts from the field to discuss critical technical issues for composite structural applications, with an emphasis on increasing overall product efficiency, quality, and safety
- To provide comprehensive, practical engineering guidance that has proven reliable for the design, fabrication, characterization, test, and maintenance of composite materials and structures
- To provide reliable data, linked to control of processes and raw materials, thereby being a comprehensive source of material property basis values and design information that can be shared within the industry
- To provide a resource for composite material and structure education with examples, applications and references to supporting engineering work
- To establish guidelines for use of information in the handbook, identifying the limitations of the data and methods
- To provide guidance on references to proven standards and engineering practices
- To provide for periodic updates to maintain the all-inclusive nature of the information
- To provide information in formats best suited for user needs
- To serve the needs of the international composites community through meetings and dialog between member industries, which use teamwork and the diverse member engineering skills to provide information for the handbook

**Notes**

1. Every effort has been made to reflect the latest information on polymer (organic), metal, and ceramic composites. The handbook is continually reviewed and revised to ensure it is complete and current.
2. CMH-17 provides guidelines and material properties for polymer (organic), metal, and ceramic matrix composite materials. The first three volumes of this handbook currently focus on, but are not limited to, polymeric composites intended for aircraft and aerospace vehicles. Metal matrix composites (MMC), ceramic matrix composites (CMC) including carbon–carbon composites (C–C), and sandwich composites are covered in Volumes 4, 5, and 6, respectively.
3. The information contained in this handbook was obtained from materials producers, industry companies and experts, reports on government-sponsored research, the open literature, and by contract with research laboratories and those who participate in the CMH-17 coordination activity. The information in this handbook has undergone vigorous technical review and was subject to membership vote.
4. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: CMH-17 Secretariat, Wichita State University, 1845 Fairmount, Wichita, KS 67260, by letter or email, [info@cmh17.org](mailto:info@cmh17.org).

**ACKNOWLEDGEMENT**

Volunteer committee members from government, industry, and academia develop, coordinate, and review all the information provided in this handbook. The time and effort of the volunteers and the support of their respective departments, companies, and universities make it possible to insure the handbook reflects completeness, accuracy, and state-of-the-art composite technology.

Support necessary for the development and maintenance of the Composite Materials Handbook (CMH-17) are provided by the Handbook Secretariat, Wichita State University. The primary source of funding for the current Secretariat contract is the Federal Aviation Administration.

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| <b>Chapter</b> | <b>Section<br/>[old section #]</b> | <b>Title</b>  | <b>Change type</b>            |
|----------------|------------------------------------|---|-------------------------------|
| <b>2</b>       |                                    | <b><u>Carbon Fiber Properties</u></b>               |                               |
|                | 2.3.2.15<br>[2.2.2.4]              | AS4C 3k/HTM45 8-Harness Satin Fabric                | Reorganization                |
|                | 2.3.2.16<br>[2.2.2.5]              | AS4C 3k/HTM45 Plain Weave Fabric                    | Reorganization                |
| <b>4</b>       |                                    | <b><u>Glass Fiber Composites</u></b>                |                               |
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|                | 4.2.2.2                            | 6781 S-2 Glass/MTM45-1 8-Harness Satin Weave Fabric | New/Miami (8/2014)            |
|                | 4.2.2.3                            | E-Glass 7781/MTM45-1 8-Harness Satin Weave Fabric   | New/Supplemental YPs (3/2015) |

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# Polymer Matrix Composites: Materials Usage, Design, and Analysis

CMH-17

COMPOSITE MATERIALS HANDBOOK



WICHITA STATE UNIVERSITY



# COMPOSITE MATERIALS HANDBOOK

## VOLUME 3. POLYMER MATRIX COMPOSITES MATERIALS USAGE, DESIGN AND ANALYSIS



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## **FOREWORD**

The Composite Materials Handbook (CMH-17) provides information and guidelines necessary to design, fabricate, and maintain components from composite and non-metallic additively manufactured (AM) materials. Its primary purposes are to provide:

- a) Rigorously reviewed material property data linked to publicly available material and process specifications,
- b) Guidelines and recommendations for material and process controls and methods for testing, data reduction, and reporting material data, and
- c) Proven methodologies, engineering solutions, best practices, lessons learned, and case studies for the design, analysis, certification, manufacture, and field support of parts and structures made from advanced materials.

In support of these purposes, the handbook is written for aerospace applications, although other applications can benefit as well. This handbook constitutes an overview of the field of advanced materials technology and engineering. It is continually updated to reflect industry advancements.

## **SUMMARY**

CMH-17 covers material characterization, design and analysis, processing, certification, and sustainment of parts and structures made from polymer, ceramic, and metal matrix composites, and non-metallic AM materials, including bonded and bolted joints, and sandwich constructions.

## **CMH-17 ORGANIZATION**

The Composite Materials Handbook organization creates, publishes, and maintains pedigreed material data as well as proven engineering information, subjected to thorough technical review, to support the development and use of advanced materials and structures in aerospace applications.

## **VISION**

The Composite Materials Handbook is the authoritative worldwide focal point for technical information on composite and non-metallic additively manufactured materials and structures in aerospace applications.

## GOALS AND OBJECTIVES

- Provide comprehensive, practical engineering guidelines that have proven reliable for the design, fabrication, characterization, test, and maintenance of composites and non-metallic AM in aerospace applications
- Provide reliable data, linked to control of processes and raw materials, thereby being a source of material property basis values and design information that satisfies the needs of the aerospace industry
- Provide content, including examples, on applications, lessons learned, and supporting engineering guidelines that outline limitations, strengths and weaknesses of composites and non-metallic AM materials and structures
- Promote safe use of composites and non-metallic AM in aerospace applications
- Promote efficient methods for design, test, analysis, and quality assurance of composite and non-metallic AM materials and structures
- Provide educational resources through both the handbook content and in-person training/content review
- Establish relationships with other standards organizations and engineering handbooks with similar goals to jointly develop and maintain consistent information

## ACKNOWLEDGEMENT

Committee members from government, industry, and academia develop, coordinate, and review all the information provided in this handbook. The time and effort of the members and the support of their respective departments, companies, and universities make it possible to ensure the handbook reflects completeness, accuracy, and industry best practices.

Support necessary for the development and maintenance of the Composite Materials Handbook (CMH-17) is provided by the Handbook Secretariat, Wichita State University. The primary source of funding for the current Secretariat contract is the Federal Aviation Administration.

## OVERVIEW OF HANDBOOK CONTENT

Composite Materials Handbook 17 is composed of a series of seven volumes.

### **Volume 1: Polymer Matrix Composites - Guidelines for Characterization of Structural Materials**

Volume 1 contains guidelines for determining the properties of polymer matrix composite material systems and their constituents, as well as the properties of generic structural elements, including test planning, test matrices, sampling, conditioning, test procedure selection, data reporting, data reduction, statistical analysis, and other related topics. Special attention is given to the statistical treatment and analysis of data. Volume 1 contains guidelines for general development of material characterization data as well as specific requirements for publication of material data in CMH-17.

### **Volume 2: Polymer Matrix Composites - Material Properties**

Volume 2 contains statistically-based data for polymer matrix composites that meets specific CMH-17 population sampling and data documentation requirements. As of the publication of Revision G, data published in Volume 2 are under the jurisdiction of the Data Review Working Group and are approved by the overall CMH-17 Coordinating Committee. New material systems will be included and additional material data for existing systems will be added as data becomes available and are approved. Selected historical data from

## Volume 3 Polymer Matrix Composites Materials Usage, Design and Analysis

previous versions of the handbook that do not meet current data sampling, test methodology, or documentation requirements, but that still are of potential interest to industry are also included in this volume.

### **Volume 3: Polymer Matrix Composites - Materials Usage, Design, and Analysis**

Volume 3 provides proven methodologies and lessons learned for the design, analysis, manufacture, and field support of fiber-reinforced, polymeric-matrix composite structures. It also provides guidelines on material and process specifications and procedures for utilization of the data presented in Volume 2. The information provided is consistent with the guidance provided in Volume 1 and is an extensive compilation of the current knowledge and experiences of the engineers and scientists who are active in composites from industry, government, and academia.

### **Volume 4: Metal Matrix Composites**

Volume 4 publishes properties on metal matrix composite material systems for which data meeting the specific requirements of the handbook are available. In addition, it provides selected guidance on other technical topics related to this class of composites, including material selection, material specification, processing, characterization testing, data reduction, design, analysis, quality control, and repair of typical metal matrix composite materials.

### **Volume 5: Ceramic Matrix Composites**

Volume 5 publishes properties on ceramic matrix composite material systems for which data meeting the specific requirements of the handbook are available. In addition, it provides selected guidance on other technical topics related to this class of composites, including material selection, material specification, processing, characterization testing, data reduction, design, analysis, quality control, and repair of typical ceramic matrix composite materials.

### **Volume 6: Polymer Matrix Composites - Sandwich Structures**

Volume 6 is an update to the cancelled Military Handbook 23, which was prepared for use in the design of structural sandwich polymer composites, primarily for flight vehicles. The information presented includes test methods, material properties, design and analysis techniques, fabrication methods, quality control and inspection procedures, and repair techniques for sandwich structures in both military and commercial vehicles. As of the time of this writing, this volume is undergoing extensive revision to add content on design, material properties, testing, and case studies.

### **Volume 7: Non-Metallic Additive Manufacturing**

Volume 7 provides the best technical guidance available on properties, design, manufacture, and use of non-metallic AM parts. It includes material properties data meeting the specific requirements of the handbook where such data is available and provides practical technical information on the design and manufacture of non-metallic AM parts. The volume focusses on the use of non-metallic AM parts in regulated applications such as civil aviation. At the time of this writing, Volume 7 is in final preparation and publication.

## Volume 3 Contents

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Metal Matrix  
Composites

**CMH-17**  
COMPOSITE MATERIALS HANDBOOK



WICHITA STATE  
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**NOT MEASUREMENT  
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CMH-17-4B  
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JULY 2013

Superseding  
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17 JUNE 2002

# COMPOSITE MATERIALS HANDBOOK

## VOLUME 4. METAL MATRIX COMPOSITES



**CMH-17**  
**COMPOSITE MATERIALS HANDBOOK**



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## FOREWORD

The Composite Materials Handbook, CMH-17, provides information and guidance necessary to design and fabricate structural components from composite materials. Its primary purposes are a) the standardization of engineering data development methodologies related to testing, data reduction, and data reporting of property data for current and emerging composite materials, b) guidance on material and process specifications and procedures for utilization of the material data presented in the handbook, and c) methodologies for the design, analysis, certification, manufacture, and field support of composite structures. In support of these objectives, the handbook includes composite materials properties that meet specific data requirements. The Handbook therefore constitutes an overview of the field of composites technology and engineering, an area that is advancing and changing rapidly. As a result, the document will be continually revised as sections are added or modified to reflect advances in the state-of-the-art.

### CMH-17 Mission

The Composite Materials Handbook 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.

### Goals and Objectives to Support CMH-17 Mission

- To periodically meet with experts from the field to discuss critical technical issues for composite structural applications, with an emphasis on increasing overall product efficiency, quality and safety.
- To provide comprehensive, practical engineering guidance that has proven reliable for the design, fabrication, characterization, test and maintenance of composite materials and structures.
- To provide reliable data, linked to control of processes and raw materials, thereby being a comprehensive source of material property basis values and design information that can be shared within the industry.
- To provide a resource for composite material and structure education with examples, applications and references to supporting engineering work.
- To establish guidelines for use of information in the Handbook, identifying the limitations of the data and methods.
- To provide guidance on references to proven standards and engineering practices.
- To provide for periodic updates to maintain the all-inclusive nature of the information.
- To provide information in formats best-suited for user needs.
- To serve the needs of the international composites community through meetings and dialogue between member industries, which use teamwork and the diverse member engineering skills to provide information for the handbook.

**Notes**

1. Every effort has been made to reflect the latest information on polymer (organic), metal, and ceramic composites. The handbook is continually reviewed and revised to ensure it is complete and current.
2. CMH-17 provides guidelines and material properties for polymer (organic), metal, and ceramic matrix composite materials. The first three volumes of this handbook currently focus on, but are not limited to, polymeric composites intended for aircraft and aerospace vehicles. Metal matrix composites (MMC), ceramic matrix composites (CMC) including carbon-carbon composites (C-C), and sandwich composites are covered in Volumes 4, 5, and 6, respectively.
3. The information contained in this handbook was obtained from materials producers, industry companies and experts, reports on Government sponsored research, the open literature, and by contract with research laboratories and those who participate in the CMH-17 coordination activity. The information in this handbook has undergone vigorous technical review and was subject to membership vote.
4. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: CMH-17 Secretariat, Materials Sciences Corporation, 135 Rock Road, Horsham, PA 19044, by letter or email, [handbook@materials-sciences.com](mailto:handbook@materials-sciences.com).

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Volunteer committee members from government, industry, and academia develop, coordinate and review all the information provided in this handbook. The time and effort of the volunteers and the support of their respective departments, companies, and universities make it possible to insure the handbook reflects completeness, accuracy, and state-of-the-art composite technology.

Support necessary for the development and maintenance of the Composite Materials Handbook (CMH-17) are provided by the handbook Secretariat, Materials Sciences Corporation. The primary source of funding for the current Secretariat contract is the Federal Aviation Administration.

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COMPOSITE MATERIALS HANDBOOK

Volume

5

# Ceramic Matrix Composites

CMH-17

COMPOSITE MATERIALS HANDBOOK



WICHITA STATE  
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# COMPOSITE MATERIALS HANDBOOK

## VOLUME 5. CERAMIC MATRIX COMPOSITES



**CMH-17**  
**COMPOSITE MATERIALS HANDBOOK**



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## FOREWORD

The Composite Materials Handbook, CMH-17, provides information and guidance necessary to design and fabricate structural components from composite materials. Its primary purposes are a) the standardization of engineering data development methodologies related to testing, data reduction, and data reporting of property data for current and emerging composite materials, b) guidance on material and process specifications and procedures for utilization of the material data presented in the handbook, and c) methodologies for the design, analysis, certification, manufacture, and field support of composite structures. In support of these objectives, the handbook includes composite materials properties that meet specific data requirements. The Handbook therefore constitutes an overview of the field of composites technology and engineering, an area that is advancing and changing rapidly. As a result, the document will be continually revised as sections are added or modified to reflect advances in the state-of-the-art.

### CMH-17 Mission

The Composite Materials Handbook 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.

### Goals and Objectives to Support CMH-17 Mission

- To periodically meet with experts from the field to discuss critical technical issues for composite structural applications, with an emphasis on increasing overall product efficiency, quality and safety.
- To provide comprehensive, practical engineering guidance that has proven reliable for the design, fabrication, characterization, test and maintenance of composite materials and structures.
- To provide reliable data, linked to control of processes and raw materials, thereby being a comprehensive source of material property basis values and design information that can be shared within the industry.
- To provide a resource for composite material and structure education with examples, applications and references to supporting engineering work.
- To establish guidelines for use of information in the Handbook, identifying the limitations of the data and methods.
- To provide guidance on references to proven standards and engineering practices.
- To provide for periodic updates to maintain the all-inclusive nature of the information.
- To provide information in formats best-suited for user needs.
- To serve the needs of the international composites community through meetings and dialogue between member industries, which use teamwork and the diverse member engineering skills to provide information for the handbook.

## Notes

1. Every effort has been made to reflect the latest information on polymer (organic), metal, and ceramic composites. The handbook is continually reviewed and revised to ensure it is complete and current.
2. CMH-17 provides guidelines and material properties for polymer (organic), metal, and ceramic matrix composite materials. The first three volumes of this handbook currently focus on, but are not limited to, polymeric composites intended for aircraft and aerospace vehicles. Metal matrix composites (MMC), ceramic matrix composites (CMC), and sandwich composites are covered in Volumes 4, 5, and 6, respectively.
3. The information contained in this handbook was obtained from materials producers, industry companies and experts, reports on Government sponsored research, the open literature, and by contract with research laboratories and those who participate in the CMH-17 coordination activity. The information in this handbook has undergone vigorous technical review and was subject to membership vote.
4. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: CMH-17 Secretariat, Wichita State University, 1845 Fairmount, Wichita, KS 67260, by letter or email, [info@cmh17.org](mailto:info@cmh17.org).

## ACKNOWLEDGEMENT

Volunteer committee members from government, industry, and academia develop, coordinate and review all the information provided in this handbook. The time and effort of the volunteers and the support of their respective departments, companies, and universities make it possible to insure the handbook reflects completeness, accuracy, and state-of-the-art composite technology.

Support necessary for the development and maintenance of the Composite Materials Handbook (CMH-17) are provided by the handbook Secretariat, Wichita State University. The primary source of funding for the current Secretariat contract is the Federal Aviation Administration.

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# Structural Sandwich Composites

**CMH-17**

COMPOSITE MATERIALS HANDBOOK



WICHITA STATE  
UNIVERSITY  
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# **COMPOSITE MATERIALS HANDBOOK**

## **VOLUME 6. STRUCTURAL SANDWICH COMPOSITES**



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## FOREWORD

The Composite Materials Handbook, CMH-17, provides information and guidance necessary to design and fabricate structural components from composite materials. Its primary purposes are a) the standardization of engineering data development methodologies related to testing, data reduction, and data reporting of property data for current and emerging composite materials, b) guidance on material and process specifications and procedures for utilization of the material data presented in the handbook, and c) methodologies for the design, analysis, certification, manufacture, and field support of composite structures. In support of these objectives, the handbook includes composite materials properties that meet specific data requirements. The Handbook therefore constitutes an overview of the field of composites technology and engineering, an area that is advancing and changing rapidly. As a result, the document will be continually revised as sections are added or modified to reflect advances in the state-of-the-art.

### CMH-17 Mission

The Composite Materials Handbook 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.

### Goals and Objectives to Support CMH-17 Mission

- To periodically meet with experts from the field to discuss critical technical issues for composite structural applications, with an emphasis on increasing overall product efficiency, quality and safety.
- To provide comprehensive, practical engineering guidance that has proven reliable for the design, fabrication, characterization, test and maintenance of composite materials and structures.
- To provide reliable data, linked to control of processes and raw materials, thereby being a comprehensive source of material property basis values and design information that can be shared within the industry.
- To provide a resource for composite material and structure education with examples, applications and references to supporting engineering work.
- To establish guidelines for use of information in the Handbook, identifying the limitations of the data and methods.
- To provide guidance on references to proven standards and engineering practices.
- To provide for periodic updates to maintain the all-inclusive nature of the information.
- To provide information in formats best-suited for user needs.
- To serve the needs of the international composites community through meetings and dialogue between member industries, which use teamwork and the diverse member engineering skills to provide information for the handbook.

**Notes**

1. Every effort has been made to reflect the latest information on polymer (organic), metal, and ceramic composites. The handbook is continually reviewed and revised to ensure it is complete and current.
2. CMH-17 provides guidelines and material properties for polymer (organic), metal, and ceramic matrix composite materials. The first three volumes of this handbook currently focus on, but are not limited to, polymeric composites intended for aircraft and aerospace vehicles. Metal matrix composites (MMC), ceramic matrix composites (CMC) including carbon-carbon composites (C-C), and sandwich composites are covered in Volumes 4, 5, and 6, respectively.
3. The information contained in this handbook was obtained from materials producers, industry companies and experts, reports on Government sponsored research, the open literature, and by contract with research laboratories and those who participate in the CMH-17 coordination activity. The information in this handbook has undergone vigorous technical review and was subject to membership vote.
4. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: CMH-17 Secretariat, Materials Sciences Corporation, 135 Rock Road, Horsham, PA 19044, by letter or email, [handbook@materials-sciences.com](mailto:handbook@materials-sciences.com).

**ACKNOWLEDGEMENT**

Volunteer committee members from government, industry, and academia develop, coordinate and review all the information provided in this handbook. The time and effort of the volunteers and the support of their respective departments, companies, and universities make it possible to insure the handbook reflects completeness, accuracy, and state-of-the-art composite technology.

Support necessary for the development and maintenance of the Composite Materials Handbook (CMH-17) are provided by the handbook Secretariat, Materials Sciences Corporation. The primary source of funding for the current Secretariat contract is the Federal Aviation Administration.

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