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ASME: Ceramic Matrix Composites

Sec. III-5 Class SN – Nonmetallic Core Components

DOE ART Gas-Cooled Reactor (GCR) Review Meeting
Virtual Meeting
July 25 – 27, 2023

ART Advanced Reactor Technologies
GAS-COOLED REACTORS

Sec III-5 HHB (Composites) Development and Status

- **About CMCs in ASME BPV-III-5**
- Background on CMC and HHB rules
- Recent Code Changes - Sec III-5 2023 (HHB)
- Task Group Focus and Current Optimization Areas
- Future Projects
- Synergies

About Non-metallic Core Components in Sec III

Graphite and composites rules integrated under Class SN Nonmetallic Core Components.

Code Classes allow a **choice of rules that provide a reasonable assurance of structural integrity and quality** commensurate with the relative importance assigned to the individual components of the advanced reactor plant.

Subsection HAB

Administrative Requirements

General Requirements

Graphite Core Assembly

Composite Core Components

- Classification of Core Components
- Quality Assurance
- Reference Standards
- Responsibilities and Duties
- Authorized Inspection
- Certification and Data Reports

Provides rules for qualification and certification

For Metals:

- HAA-1130 LIMITS OF THESE RULES :

“The rules of this Subpart and Subsection HH provide requirements for new construction and include consideration of mechanical and thermal stresses due to cyclic operation. They do not cover deterioration that may occur in service as a results of environmental effects such as radiation, corrosion, erosion or instability of materials.”

For Graphite and Composite Materials:

- HAB-1130 LIMITS OF THESE RULES :

“The rules of this Subpart and Subsection HH provide requirements for new construction and include consideration of mechanical and thermal stresses due to cyclic operation. They include consideration of deterioration that may occur in service as a result of environmental considerations.”

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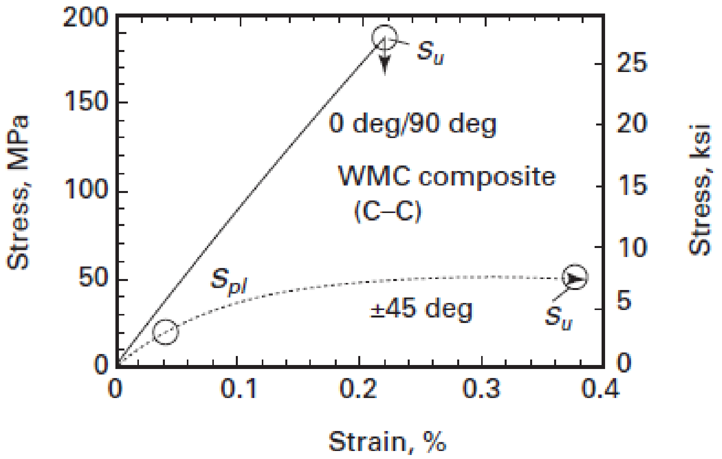
ASME - CMCs: Two permissible material systems

C-C Composites

Weak matrix



Pros Eliminates metals from the core (specific components)

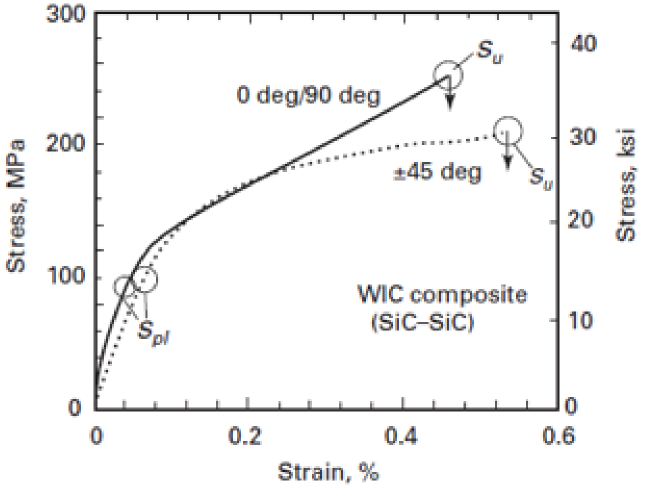
Good residual properties (greater strength and fracture resistance than graphite)

Good industrial experience

Cons Less tolerant to radiation damage (< ~8-10dpa, E=0.1 MeV)

SiC-SiC Composites

Weak interface



Pros Good oxidation resistance

Higher cracking stress than C-C

Great radiation damage resistance (up to ~40dpa, E=0.1 MeV)

Longer Life: e.g. control rods need no change-out

Cons Higher cost than C-C

Less industrial experience

Some key issues about composites

ASME specification for C-C and SiC-SiC composites

- C-C and SiC-SiC composites are complex (fibers, matrix, porosity) with a wide range of constituents with different properties and many distinctly different densification techniques.
- Reinforcement architectures can vary widely with marked anisotropy giving anisotropic physical and mechanical properties.

- Component properties can vary widely based on constituents, architecture, and processing.
- Component requirements can vary widely, depending on design requirements and composite materials and architectures.

DESIGN AND SPECIFICATION CONCERNS

Composites are a “new” material system that are tailored for a specific component. Composites have different design rules and different failure mechanisms than metals and monolithic ceramics.

Some key concepts introduced in the HHB rules

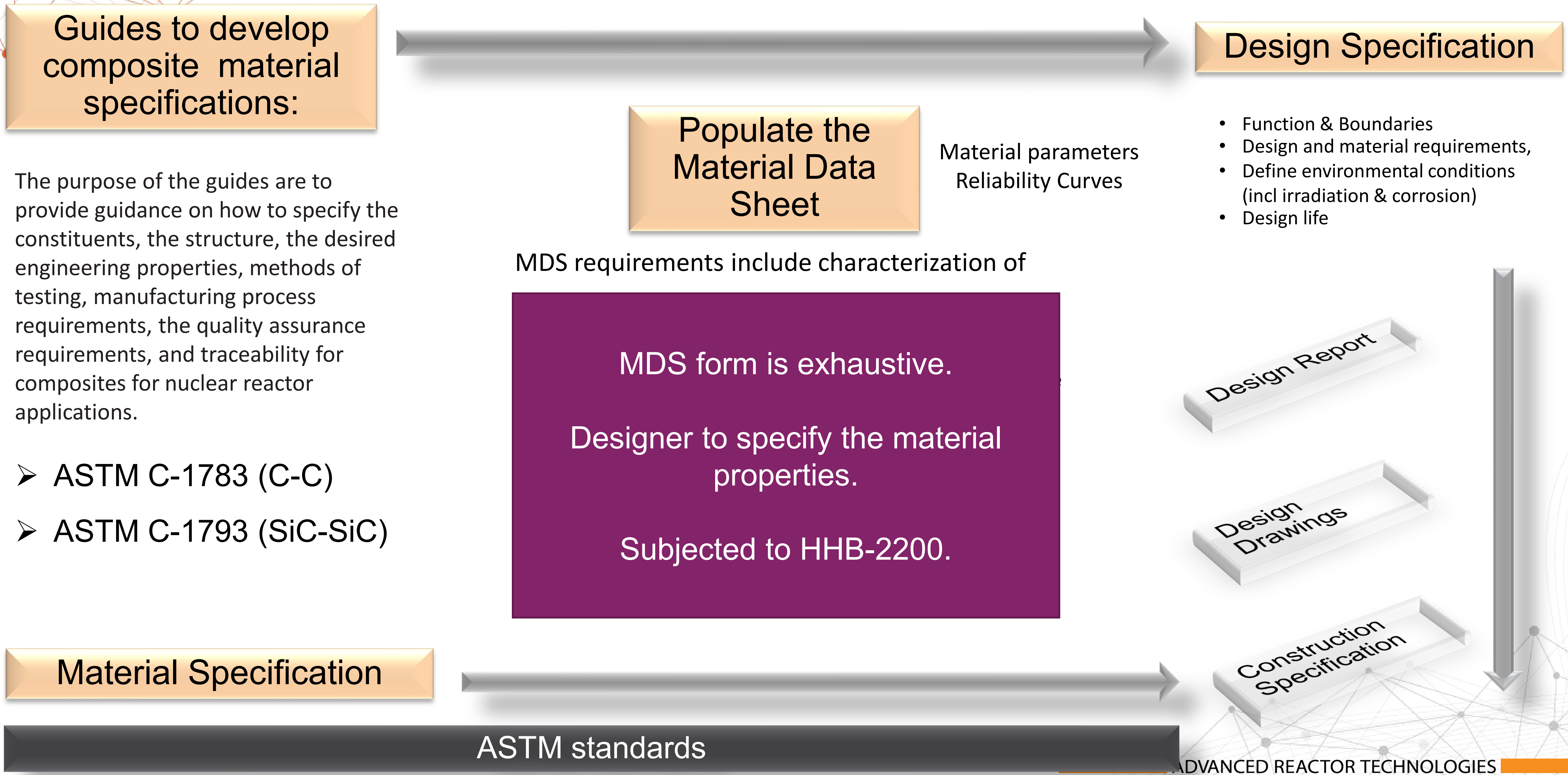
The Design and Materials code for the use of CMCs (SiC-SiC and C-C) core components in HTR (like the graphite code)

The code is structured

- To allow for multiple applications and continual development
- To allow for future applications and the unique nature of the material, the code is process based
  - Guidance for permissibility of the materials, how to specify, how to qualify

- Design provides for two design approaches
  - Design by Analysis (Simplified POF Assessment)
  - Design by Test
- The rules are probabilistic as failure is derived from the variability in the material strength.
- It includes the evaluation of environmental effects such as irradiation, oxidation / chemical attack and STT (in the case of CMCs).

HHB Rules: Requirements and Specification of Materials



Guides to develop composite material specifications:

The purpose of the guides are to provide guidance on how to specify the constituents, the structure, the desired engineering properties, methods of testing, manufacturing process requirements, the quality assurance requirements, and traceability for composites for nuclear reactor applications.

- ASTM C-1783 (C-C)
- ASTM C-1793 (SiC-SiC)

Populate the Material Data Sheet

Material parameters
Reliability Curves

Design Specification

- Function & Boundaries
- Design and material requirements,
- Define environmental conditions (incl irradiation & corrosion)
- Design life

MDS requirements include characterization of

MDS form is exhaustive.

Designer to specify the material properties.

Subjected to HHB-2200.

Design Report

Design Drawings

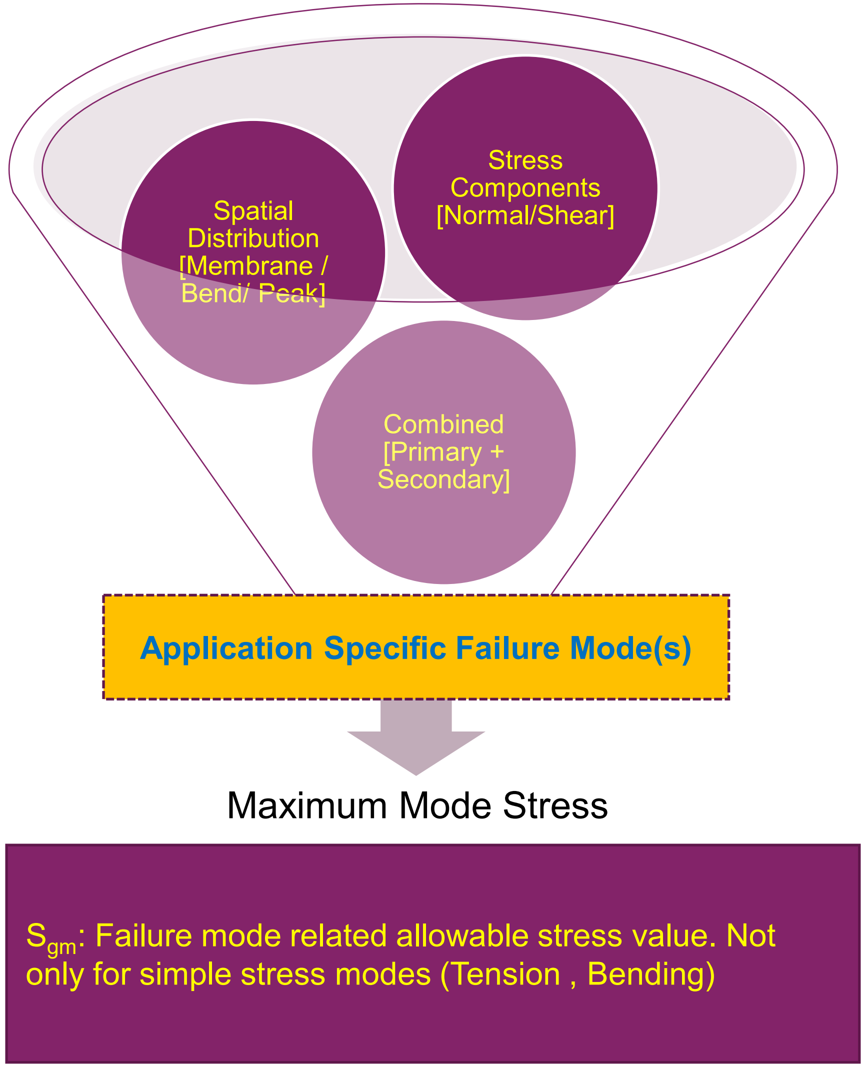
Construction Specification

Material Specification

ASTM standards

Design by Analysis Approach

- *Identify potential failure modes and loading criteria*
  - *Static*
  - *Time-dependant*
  - *Primary and secondary loads*
- *Define the component classification and acceptable POF*
  - *SRC-1: important to safety of the reactor core*
  - *SRC-3: not important to the safety of the reactor core*
- *Develop models for stress and strength*
  - *It is key to complete the stress analysis - the stress at failure need to be determined for the failure mode*

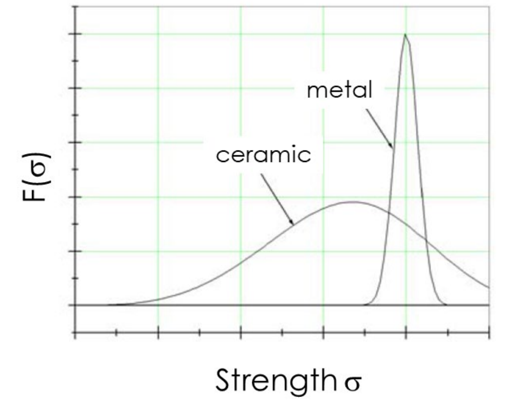


S_{gm}: Failure mode related allowable stress value. Not only for simple stress modes (Tension , Bending)

Geringer et al., NED 405, 112158, 2023

Design by Analysis Approach

- *Statistically characterize the material performance*



For metals and ductile materials, the scattering of strength values is within a small region around the mean value.

For ceramic materials the strength distribution differs in such a way that very small failure values can occur.

- *Determine the design allowable stresses based on component POF*

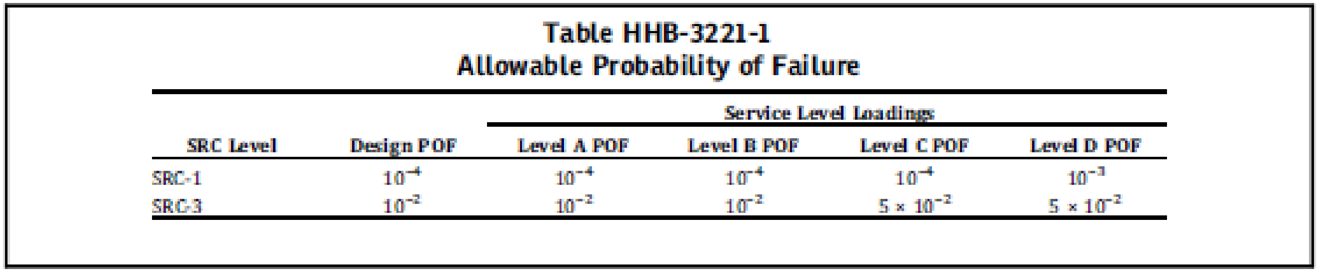


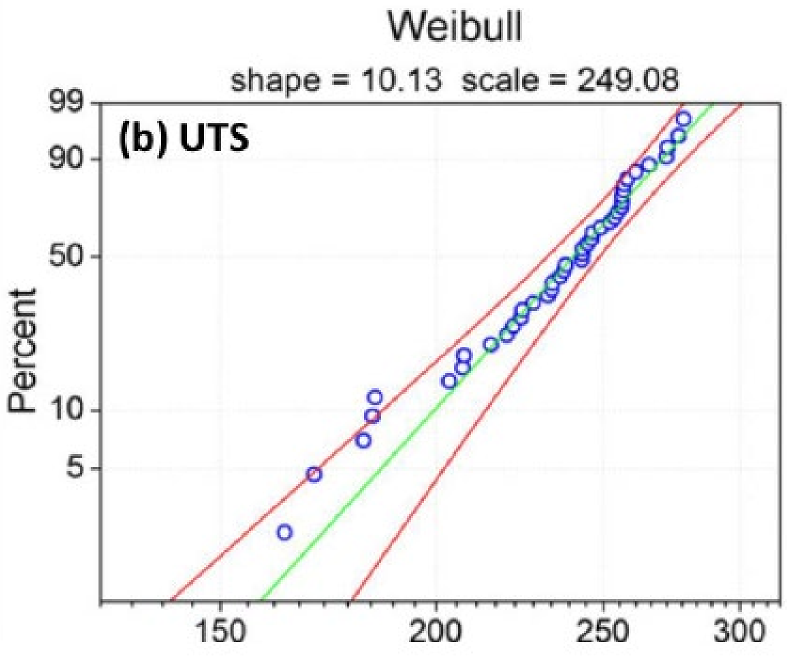
Table HHB-3221-1
Allowable Probability of Failure

SRC Level	Design POF	Service Level Loadings Level A POF	 Level B POF	 Level C POF	 Level D POF
SRC-1	10^{-4}	10^{-4}	10^{-4}	10^{-4}	10^{-3}
SRC-3	10^{-2}	10^{-2}	10^{-2}	5×10^{-2}	5×10^{-2}

- *Structural Reliability Assessment*

The variability in material strength is characterised by the material reliability curve.

- Proposed. Use a Weibull distribution to characterise the material strength (Ho, Schmidt, Nemeth & Bratton)
- Conservatism introduced using 95% confidence limits.



Tensile strength of CVI SiC-SiC composite tube with HNS fiber

Singh et al, Int. J. Appl. Ceram. Technol. (2018)

Geringer et al., NED 405, 112158, 2023

HHB Rules: Design by Test

- Design by Test focuses on subcomponents / components
- Similar requirements to the derivation of S_{gm}
  - Multiple components
  - Close similarity to actual components
  - May adjust for temperature and other environmental conditions
- Experimental proof of strength and demonstration of POF
  - Statistical analysis of the test results shall provide values within 95% certainty by lower bound.
- Experimental Proof of Strength, Load Rating
  - Method geared towards production component testing

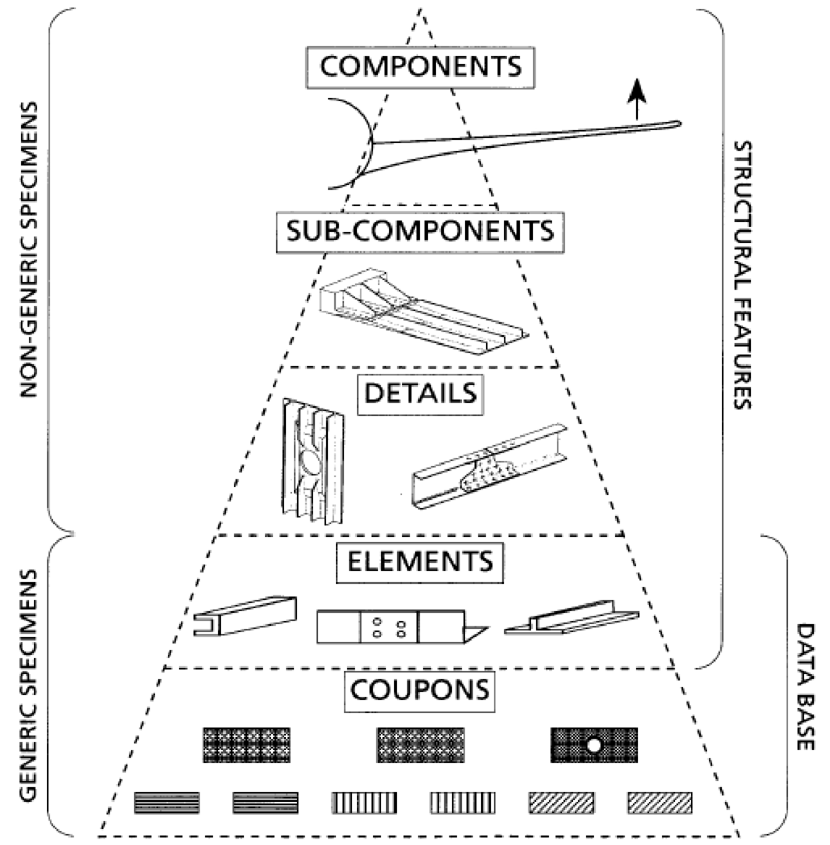


FIGURE 8.1.1 *The “pyramid” of tests in the “building-block” approach.*

CMH-HDBK-17 Volume 5

Geringer et al., NED 405, 112158, 2023

Current status code rules for CMCs (HHB): Pros and Cons

Pros:

- Code rules established within the ASME design framework
- Allows the use of fiber reinforced CMCs for structural core components in HTRs.
- Provides a method to qualify new CMCs, acceptable for use of nuclear application (NQA-1)

Cons:

- Not fully optimized (e.g. design by test, maximum failure mode, conservatism)
- Lacking technical basis and requires benchmarking
- Not endorsed by NRC (not part of initial review)

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2023 Code Change – Failure Mode Stress (Composites)

Graphite **Composites**

Technical Requirements

Graphite Core Components

HHA

Graphite Core Assembly

Maximum deformation energy theory (equivalent stress)

- Design by Analysis
  - Simple assessment
  - Full assessment
- Design by test

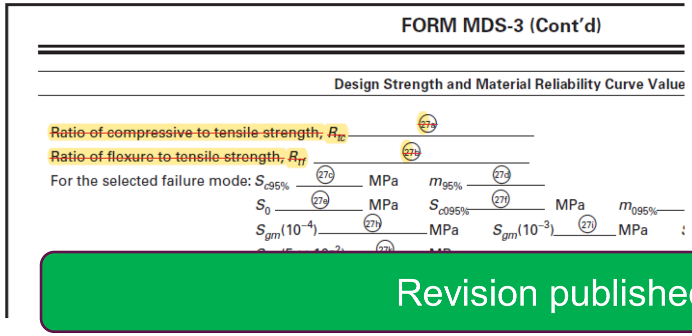
Composite Core Components

HHB

CMC Components

Failure Mode Stress Theory (equivalent stress do not apply)

- Design by Analysis
  - Simple assessment
- Design by test



FORM MDS-3 (Cont'd)

Design Strength and Material Reliability Curve Value

~~Ratio of compressive to tensile strength, R_{tc}~~ ~~(27a)~~ ______

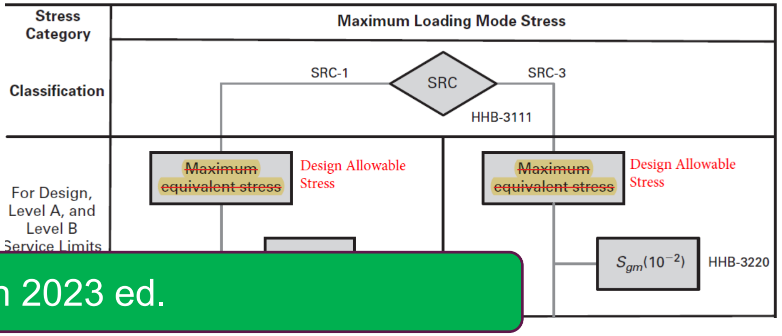
~~Ratio of flexure to tensile strength, R_{tf}~~ ~~(27b)~~ ______

For the selected failure mode: $S_{c95\%}$ (27c) ______ MPa $m_{95\%}$ (27d) ______

S_0 (27e) ______ MPa $S_{c095\%}$ (27f) ______ MPa $m_{095\%}$ ______

$S_{gm}(10^{-4})$ (27h) ______ MPa $S_{gm}(10^{-3})$ (27i) ______ MPa

Figure HHB-3221-1
Allowable Stresses Flowchart for SRC-1 and SRC-3 Composite Core Components



Revision published in 2023 ed.

Graphite uses the maximum deformation energy theory that combines stresses. This allows for an arbitrary stress state at a point to be converted to an equivalent stress which is then directly compared to the results of a uniaxial strength test. (HHA-3213)

- HHA Simple Assessment: calculate the peak equivalent stress
- HHA Full Assessment: calculate the combined equivalent stress

Composites design approach requires comparing the maximum stresses resulting from the loading of the component to the stress at failure of the material. It does not make use of the theory for combining stresses. The stress at failure needs to be determined for the mode at failure exercised by the applied stress. (HHB—3213)

- HHB Simple assessment: calculate the maximum loading mode stress

The equivalent stress approach should not be used in HHB.

The ratio of strengths is not applicable to composites

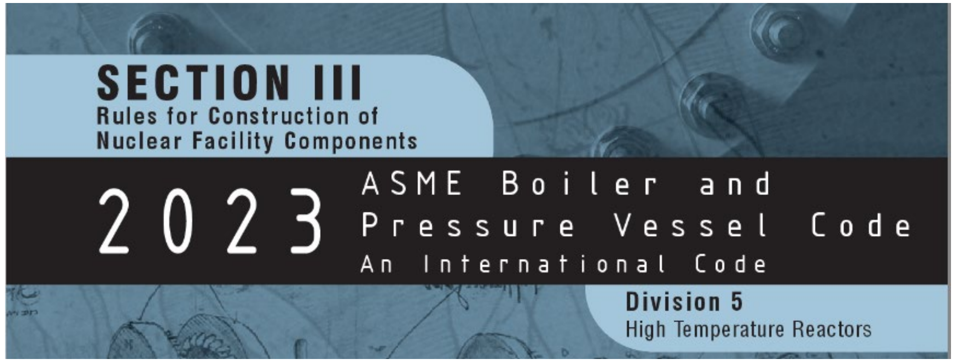
HHB C-C CMC Non-mandatory Appendices

ASME BPVC.III.5-2023

Published in 2023 ed.

NONMANDATORY APPENDIX HHB-D
CARBON–CARBON (C–C) COMPOSITE MATERIALS

NONMANDATORY APPENDIX HHB-E
CARBON-CARBON (C–C) COMPOSITE MATERIALS IRRADIATION AND ENVIRONMENTAL EFFECTS

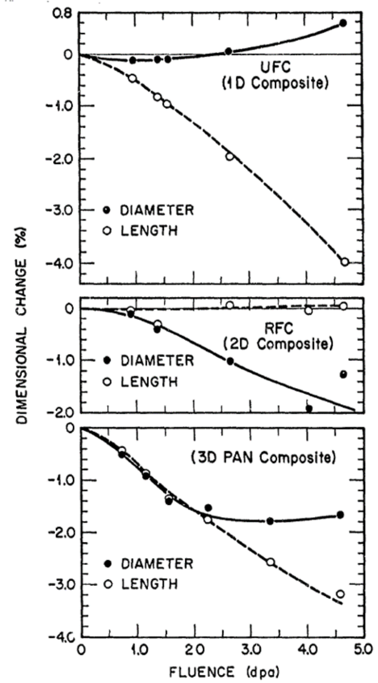


SECTION III
Rules for Construction of
Nuclear Facility Components

2023 ASME Boiler and
Pressure Vessel Code
An International Code

Division 5
High Temperature Reactors

Article	Paragraphs	Applicability
New NMA Proposed		
(New) HHB-D C-C CMC Materials and Applications (general information on the composition, architecture, manufacture and properties of C-C composites.)	-1000 Introduction -2000 Manufacture -3000 Properties -4000 Potential Applications of composites in HTRs -5000 References	Address C-C specific aspects and list strength as well as physical material properties missing in HHB-B. It highlights potential applications of C-C composites in HTR, but some could be applicable for SiC-SiC.
(New) HHB-E C-C CMC Irradiation and Environmental Effects (Information on the effects of fast neutron irradiation on C-C composites)	-1000 Introduction -2000 Irradiation Induced Damage -3000 Irradiation Induced Dimensional Changes -4000 Irradiation Induced Changes in Physical Properties -5000 Irradiation Induced Changes in Mechanical Properties -6000 Effects of Chemical Attack/Oxidation on C/C Composites -7000 References	Specifically discuss the irradiation induced damage effects caused to C-C and highlights the typical irradiation induced changes to physical and mechanical properties. Specifically discuss corrosion / oxidation response on C-C composites.



T.D. Burchell, Physica Scripta 64, 17–25, 1996.

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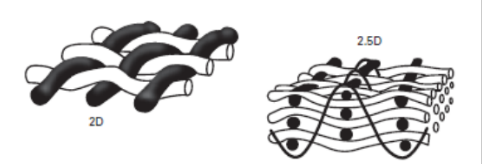
TPOC: Josina Geringer

WG-NDM: Task Group on Composites

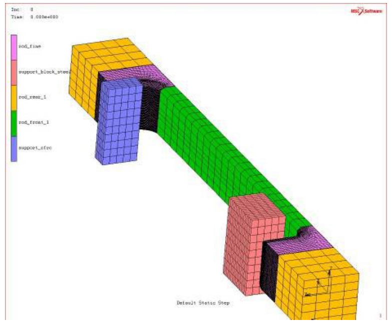
The composites task group is a subset of the nonmetallic design and materials working group (NDM-WG) with specific focus to address mission relevant activities as it relates to Sec III.5 HAB and HHB on ceramic matrix composites.

Objective:

- Bring vendor community together on code related questions
- Identify type/current composite applications and code related issues that have been uncovered
- Identify areas that require review and/or further optimization
- Discuss strategies to demonstrate or benchmark the code methodology.



Examples of Fiber Architecture



Material by design

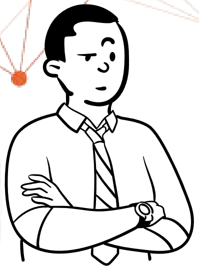
- Qualification Methodology:
  - Is it possible to optimize and/or accelerate the qualification process by reducing the material qualification effort?
  - How can technologies & analytical methods be used to reduce testing efforts?
  - What is truly mandatory or non-mandatory in the code?
- Composite design rule assessment
  - Does the “simplified assessment” design approach clearly explain how to address anisotropic differences in mechanical properties?
  - Is there sufficient detail for the design by test methodology?
  - When should which method be applied?
- Industry: code readiness
  - Identify optimization areas.

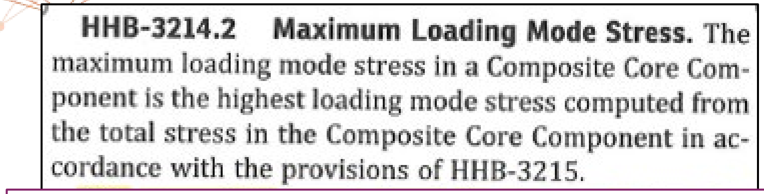
Identified focus areas to optimize for 2025

- Design by Analysis – Structural Assessment Procedure
- Design by Analysis vs Design by Test
- Material Fabrication and Testing

Aim to revise for 2025 edition.

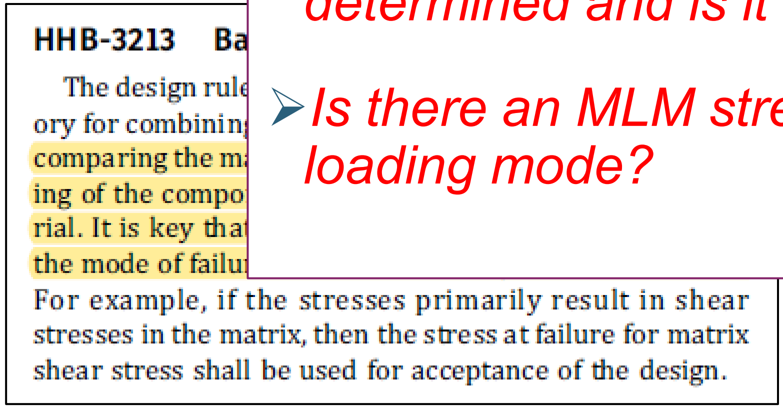
Design by Analysis – Structural Assessment Procedure





HHB-3214.2 Maximum Loading Mode Stress. The maximum loading mode stress in a Composite Core Component is the highest loading mode stress computed from the total stress in the Composite Core Component in accordance with the provisions of HHB-3215.

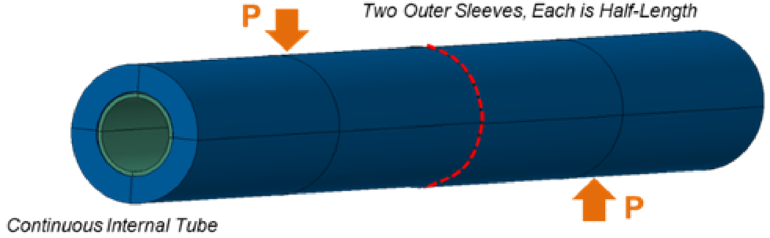
- *How is Maximum Loading Mode (MLM) stress determined and is it a singular global value?*
- *Is there an MLM stress for each direction and loading mode?*



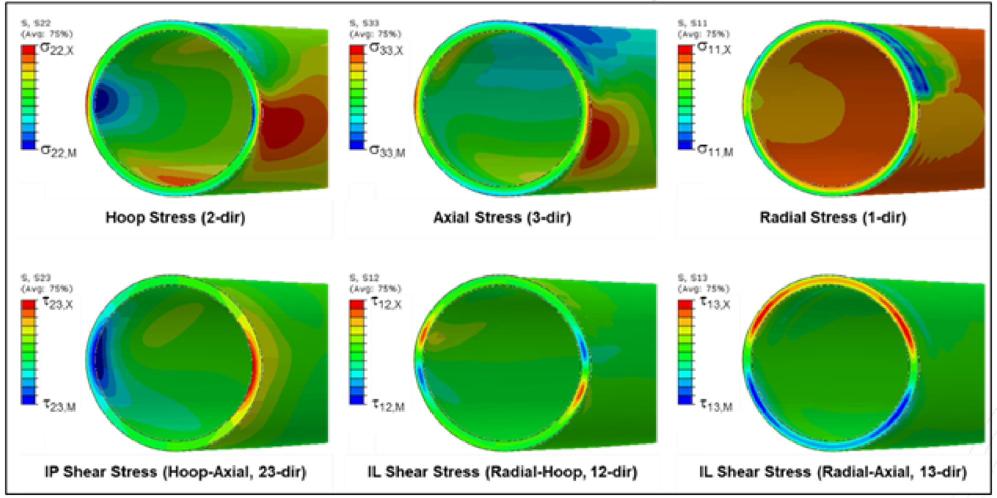
HHB-3213 Ba

The design rule
ory for combinin
comparing the m
ing of the compo
rial. It is key that
the mode of failu

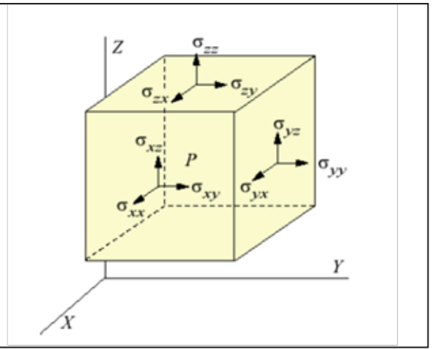
For example, if the stresses primarily result in shear stresses in the matrix, then the stress at failure for matrix shear stress shall be used for acceptance of the design.



Stress Contours for the Internal Tube, Mid-Length Section Cut



Courtesy MR&D Inc.

Maximum Loading Mode Stress	σmax tensile (xx,yy,zz), σmax compression (xx,yy,zz), σmax shear (x-y, x-z, y-z, y-z, z-x, z-y)	
Design Allowable Stress (Reliability Factor)	Sgm tensile (xx,yy,zz), Sgm compression (xx,yy,zz), Sgm shear (x-y, x-z, y-z, y-z, z-x, z-y)	

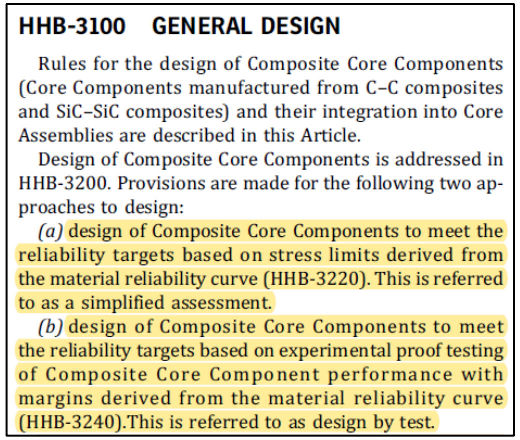
One should compare peak values for all directional stresses:

Peak stress being the component stresses with corresponding POF-adjusted allowable stresses.

Not just one failure mode.

Design-by-Analysis and/or Design-by-Test

- Design by Analysis (HHB-3220) is unavoidable for larger components
  - Testing infrastructure to simultaneously apply all the necessary loads to properly qualify a component, does not exist
  - To create such test facility or setup often complex, expensive and introduce additional risk.
- Unfortunately, it requires extensive material characterization due to the added complexity of composite materials
  - Orthotropic vs. isotropic, more strengths to measure…
- A combined Analysis/Testing approach is desired to reduce the amount of material testing through supplemental subcomponent and component level testing.



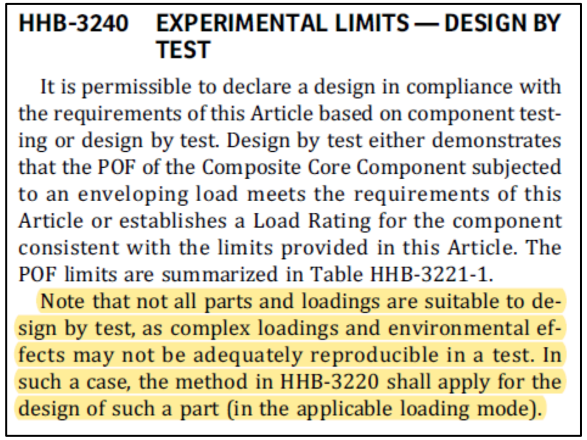
HHB-3100 GENERAL DESIGN

Rules for the design of Composite Core Components (Core Components manufactured from C–C composites and SiC–SiC composites) and their integration into Core Assemblies are described in this Article.

Design of Composite Core Components is addressed in HHB-3200. Provisions are made for the following two approaches to design:

(a) design of Composite Core Components to meet the reliability targets based on stress limits derived from the material reliability curve (HHB-3220). This is referred to as a simplified assessment.

(b) design of Composite Core Components to meet the reliability targets based on experimental proof testing of Composite Core Component performance with margins derived from the material reliability curve (HHB-3240).This is referred to as design by test.



HHB-3240 EXPERIMENTAL LIMITS — DESIGN BY TEST

It is permissible to declare a design in compliance with the requirements of this Article based on component testing or design by test. Design by test either demonstrates that the POF of the Composite Core Component subjected to an enveloping load meets the requirements of this Article or establishes a Load Rating for the component consistent with the limits provided in this Article. The POF limits are summarized in Table HHB-3221-1.

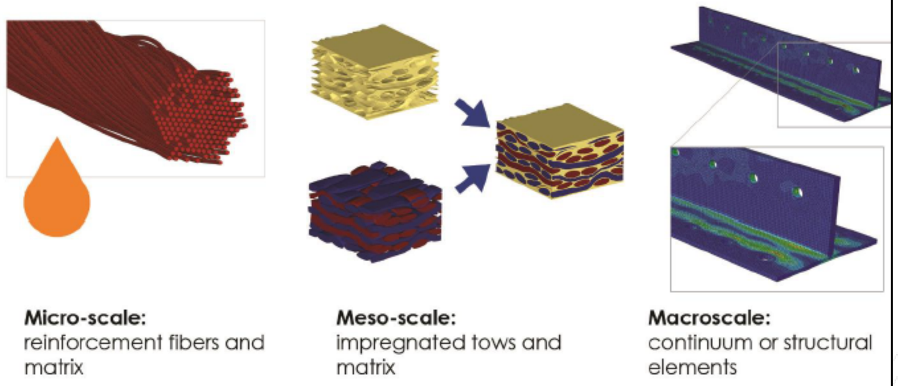
Note that not all parts and loadings are suitable to design by test, as complex loadings and environmental effects may not be adequately reproducible in a test. In such a case, the method in HHB-3220 shall apply for the design of such a part (in the applicable loading mode).

ASME BPV III-5 (2021)

Optimization area:

Combined Analysis/Testing approach is not explicitly outlined in the code.

Requires emphasis!



Micro-scale: reinforcement fibers and matrix

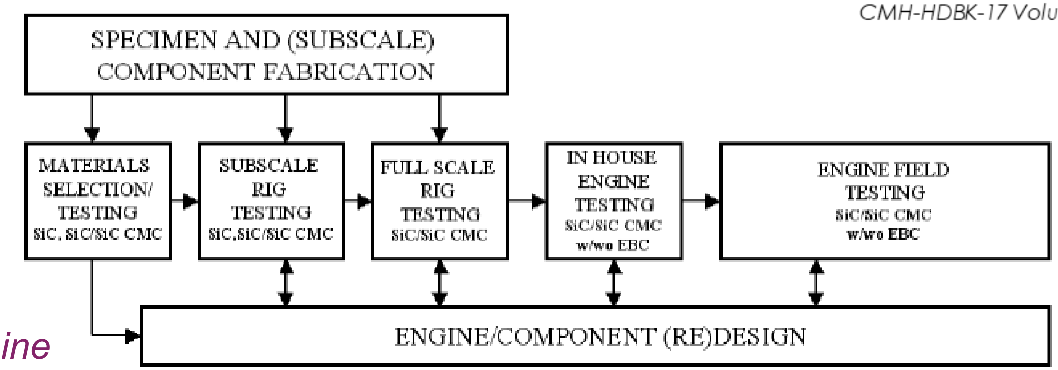
Meso-scale: impregnated tows and matrix

Macroscale: continuum or structural elements

© Albany Engineered Composites Inc. 2016

FIGURE 3.4.6 *Visual examples of micro, meso and macroscale modeling*

CMH-HDBK-17 Volume 5

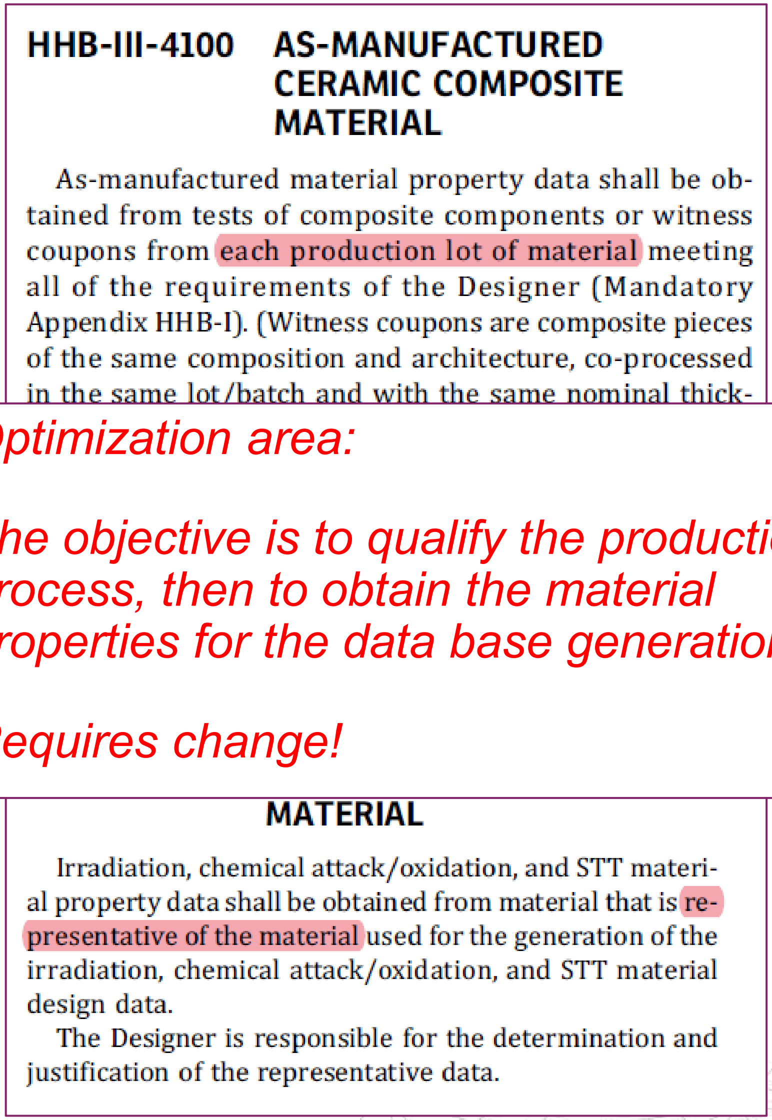


Case study: Ceramic Stationary Gas Turbine

Material Fabrication and Testing

- MDS data is utilized to determine POF and allowable stress considered in analysis
- ASME requires generation of the MDS forms **per lot**; co-processed composite material of the same composition and architecture
  - MDS form associated with production component
  - Generation of design strength, modulus and reliability curves specific to production lot
  - Includes environmental effects such as temperature, oxidation, irradiation etc.
    - Testing at maximum temp increments of 200°C
- This approach differs from that described in CMH-17; where qualification testing is performed to accumulate testing data (generation of a data base) utilized to generate design allowables, followed by acceptance testing of production components

Example paragraphs:



HHB-III-4100 AS-MANUFACTURED CERAMIC COMPOSITE MATERIAL

As-manufactured material property data shall be obtained from tests of composite components or witness coupons from each production lot of material meeting all of the requirements of the Designer (Mandatory Appendix HHB-I). (Witness coupons are composite pieces of the same composition and architecture, co-processed in the same lot/batch and with the same nominal thick-

MATERIAL

Irradiation, chemical attack/oxidation, and STT material property data shall be obtained from material that is representative of the material used for the generation of the irradiation, chemical attack/oxidation, and STT material design data.

The Designer is responsible for the determination and justification of the representative data.

Optimization area:

The objective is to qualify the production process, then to obtain the material properties for the data base generation

Requires change!

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Benchmark Study

Benchmark study

- Generate Micromechanics Models for CMC material properties in as-fabricated and irradiated condition from test data.
- Demonstrate allowable stress using the POF methodology
- Determine failure mode and perform structural assessment applying code rules

Provide technical support basis for ASME

Question on code conservatism / knockdown factors:

ASME:

SRC-1 – Design POF = 10^{-4}

SRC-3 – Design POF = 10^{-2}

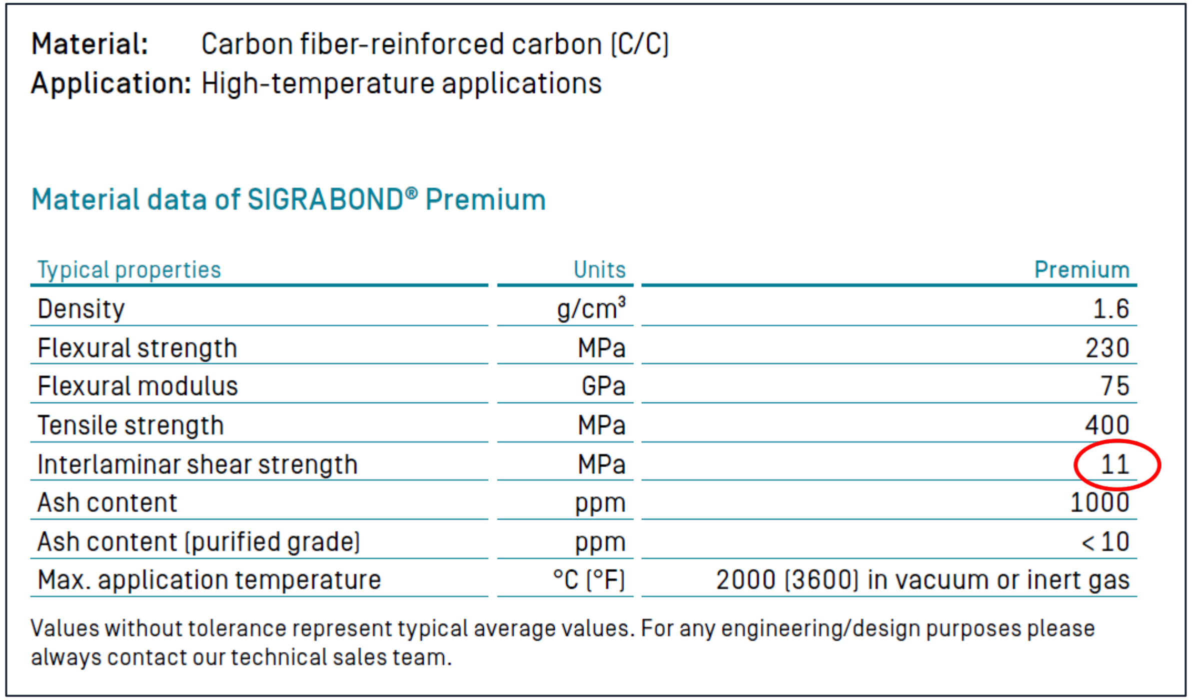
A-basis allowables (CMH-17)

Sample collection – Design POF = $1.0*10^{-2}$

Aircraft structures (U.S. DOT)

Composites Design POF = $1.0*10^{-7}$ or $1.0*10^{-9}$

U.S. DOT guidance: “The agency certifying the structure should be responsible for setting this overall specification for the structure.”



Material: Carbon fiber-reinforced carbon (C/C)
Application: High-temperature applications

Material data of SIGRABOND® Premium

Typical properties	Units	Premium
Density	g/cm³	1.6
Flexural strength	MPa	230
Flexural modulus	GPa	75
Tensile strength	MPa	400
Interlaminar shear strength	MPa	11
Ash content	ppm	1000
Ash content (purified grade)	ppm	< 10
Max. application temperature	°C (°F)	2000 (3600) in vacuum or inert gas

Values without tolerance represent typical average values. For any engineering/design purposes please always contact our technical sales team.

https://www.sglcarbon.com/en/markets-solutions/material/sigrabond-carbon-fiber-reinforced-carbon/

Example:
Interlaminar shear on C-C presents a challenge for designers.

For SRC-1: If $m^* = 20$ then $Sg(10^{-4}) = 6.6$ MPa
If $m^* = 10$ then $Sg(10^{-4}) = 3.85$ MPa

m = Weibull modulus (95% lower bound confidence interval)*

Other Identified Challenges

- Are composite components always Material by Design?
  - With sufficient standardization in manufacturing specifications, testing specifications, and design / analysis / qualification approaches, composites could move to material in design

→ A long-term process?

- Challenges
  - Reconciling the depth of the material specification with the proprietary nature of composite fabrication techniques
  - Current status of composite material testing standards
  - Availability of elevated temperature testing facilities
  - Timeline, cost, and dimensional limitations associated with obtaining irradiated material properties

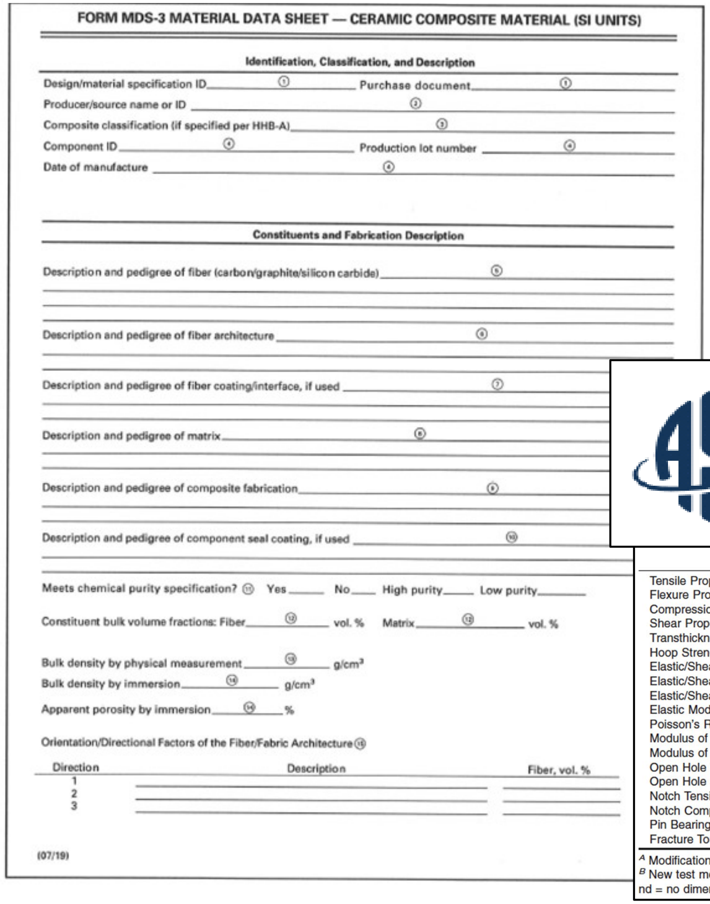
Sec III-5 HHB (Composites) Development and Status

- About CMCs in ASME BPV-III-5
- Background on CMC and HHB rules
- Recent Code Changes - Sec III-5 2023 (HHB)
- Task Group Focus and Current Optimization Areas
- Future Projects
- **Synergies**

CMC Synergistic Activities & Industry Alignment

SETTING THE STANDARD

SUBSECTION HH CLASS SN
NONMETALLIC CORE COMPONENTS –
SUBPART B COMPOSITE MATERIAILS



FORM MDS-3 MATERIAL DATA SHEET — CERAMIC COMPOSITE MATERIAL (SI UNITS)

Identification, Classification, and Description

Design/material specification ID ① Purchase document ①
Producer/source name or ID ②
Composite classification (if specified per HHB-A) ③
Component ID ④ Production lot number ④
Date of manufacture ④

Constituents and Fabrication Description

Description and pedigree of fiber (carbon/graphite/silicon carbide) ⑤
Description and pedigree of fiber architecture ⑥
Description and pedigree of fiber coating/interface, if used ⑦
Description and pedigree of matrix ⑧
Description and pedigree of composite fabrication ⑨
Description and pedigree of component seal coating, if used ⑩

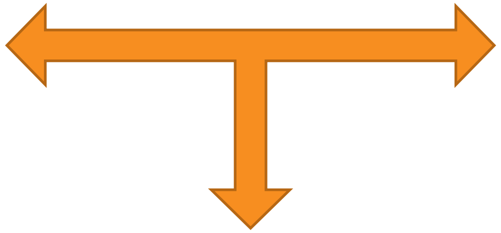
Meets chemical purity specification? ⑪ Yes ___ No ___ High purity ___ Low purity ___
Constituent bulk volume fractions: Fiber ⑫ vol. % Matrix ⑫ vol. %

Bulk density by physical measurement ⑬ g/cm³
Bulk density by immersion ⑭ g/cm³
Apparent porosity by immersion ⑭ %

Orientation/Directional Factors of the Fiber/Fabric Architecture ⑮

Direction	Description	Fiber, vol. %
1		
2		
3		

(07/19)



COMPOSITE MATERIALS HANDBOOK

CMH-17 Ceramic Matrix Composites Volume 5 Handbook

Handbook Sections – Part C. Testing:

- Chapter 8 – Thermo-Mechanical-Physical Test Methods – Overview
- Chapter 9 – Material Testing & Characterization for Submission of Data to CMH-17
- Chapter 10 – Evaluation of Reinforcements
- Chapter 11 – Evaluation of Matrix Materials
- Chapter 12 – Evaluation of Interface Material
- Chapter 13 – Evaluation of Composites
- 14 – Subcomponent Testing – Overvi
- 15 – Machining and Grinding

Section 13 – Evaluation of Composites

- 13.2 – Fiber Volume Fraction (ASTM D3171 & Optical Methods)
- 13.3 – Coefficient of Thermal Expansion (CTE) (ASTM E228)
- 13.4 – Thermal Conductivity (Multiple ASTMs)
- 13.5 – Specific Heat (Multiple ASTMs)
- 13.7 – Compression (ASTM C1358)
- 13.8 – Flexure (ASTM C1341)
- 13.10 – Interlaminar Tension (ASTM C1468/D6415)
- 13.11 – Notched Testing (Multiple ASTMs)
- 13.12 – Interlaminar Fracture Toughness
- 13.14 – Creep Testing (ASTM C1337)
- 13.15 – Fatigue Testing (ASTM C1360)
- 13.17 – Wear Testing
- 13.18 – Bearing Testing
- 13.19 – Biaxial Testing

Committee C28 Advanced Ceramic Standards

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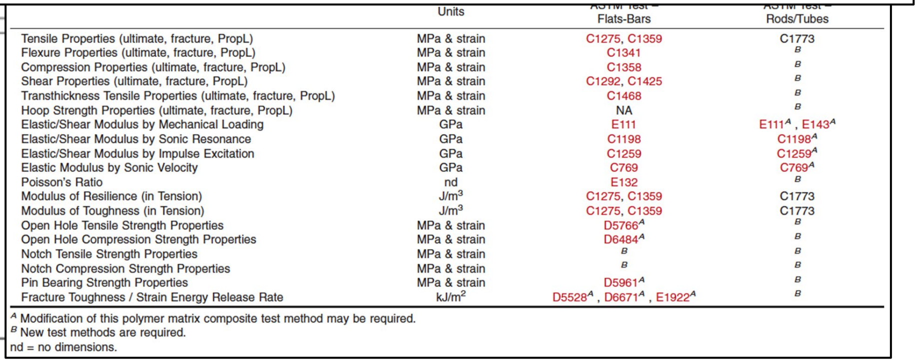

	Units	Flats-Bars	Rods/Tubes
Tensile Properties (ultimate, fracture, PropL)	MPa & strain	C1275, C1359	C1773
Flexure Properties (ultimate, fracture, PropL)	MPa & strain	C1341	[B]
Compression Properties (ultimate, fracture, PropL)	MPa & strain	C1358	[B]
Shear Properties (ultimate, fracture, PropL)	MPa & strain	C1292, C1425	[B]
Transthickness Tensile Properties (ultimate, fracture, PropL)	MPa & strain	C1468	[B]
Hoop Strength Properties (ultimate, fracture, PropL)	MPa & strain	NA	[B]
Elastic/Shear Modulus by Mechanical Loading	GPa	E111	E111[A], E143[A]
Elastic/Shear Modulus by Sonic Resonance	GPa	C1198	C1198[A]
Elastic/Shear Modulus by Impulse Excitation	GPa	C1259	C1259[A]
Elastic Modulus by Sonic Velocity	GPa	C769	C769[A]
Poisson's Ratio	nd	E132	[B]
Modulus of Resilience (in Tension)	J/m³	C1275, C1359	C1773
Modulus of Toughness (in Tension)	J/m³	C1275, C1359	C1773
Open Hole Tensile Strength Properties	MPa & strain	D5766[A]	[B]
Open Hole Compression Strength Properties	MPa & strain	D6484[A]	[B]
Notch Tensile Strength Properties	MPa & strain	[B]	[B]
Notch Compression Strength Properties	MPa & strain	[B]	[B]
Pin Bearing Strength Properties	MPa & strain	D5961[A]	[B]
Fracture Toughness / Strain Energy Release Rate	kJ/m²	D5528[A], D6671[A], E1922[A]	[B]

[A] Modification of this polymer matrix composite test method may be required.
[B] New test methods are required.
nd = no dimensions.

CMH-17 works towards partnership with C28.07 - Joint meetings

Conclusion

- ASME Sec III-5 HHB = Class SN Nonmetallic Core Components
  - Rules includes environmental in-service conditions
  - HHB has not been reviewed by NRC. (Not endorsed)

- It is structured to allow for multiple applications and continual development as it is process based.
  - The code needs to be flexible (unique nature of the CMCs)

  - It currently provides two design approaches.

- There are new code additions and revisions in the ASME BPV 2023 edition.

- From strong community interaction, optimization areas have been identified.
  - Target - 2025 edition

- Technical basis (for ASME) is lacking and could benefit from a benchmark study to validate the approach

- Aiming to improve industry alignment (ASTM & CMH-17 community)

Questions?

Thank you for your attention
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