July 14, 2022 – Session 3

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ASME Code Development Status

Sec. III-5 Class SN – Nonmetallic Core Components

ART Advanced Reactor Technologies
GAS-COOLED REACTORS

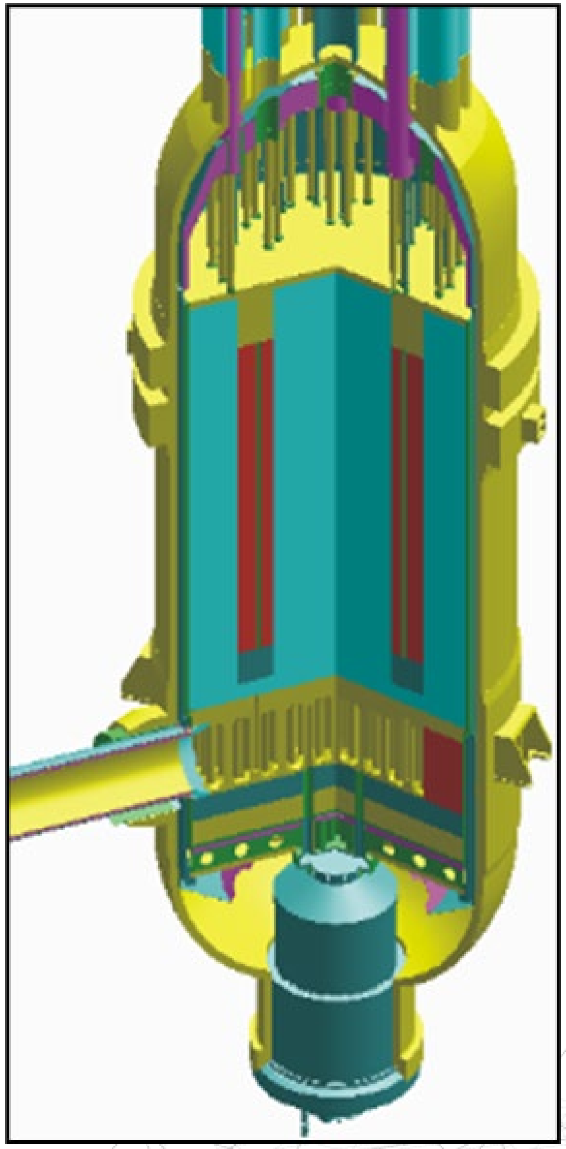
ASME Sec. III-5 Nonmetallic Design Rules Status

Nonmetallic Core Component Code Relevancy

- ASME Sec. III Nuclear Codes Div. 5 HTR
- Design and Materials code for the use of graphite and CMC components in HTR
- The code is process based to allow for future applications and the unique nature of the material.
- 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 stress-time-temperature (in the case of CMCs).

Technical Approach and Progress

- **Subsection HAB**
  – Revising Data Report Forms required for Certification
- **Subsection HHA (Graphite)**
  – Several Task Group activities ongoing to address identified optimization areas.
  – New code changes and clarification
- **Subsection HHB (Composites)**
  – Initiated Task Group to preliminary review code for optimization areas with the development of new HTR technologies.
  – Continuation of code changes/amendments (corrections & non-mandatory appendices)



NRC Endorsement of ASME Section III, Division 5 -Status

- Since last review NRC completed its review of ASME Section III, Division 5 (2017 Edition) and accompanying Code Cases

U.S. NUCLEAR REGULATORY COMMISSION

DRAFT REGULATORY GUIDE DG-1380

Proposed Revision 2 to Regulatory Guide 1.87

Issue Date: August 2021
Technical Lead: Jeffrey Poehler

ACCEPTABILITY OF ASME CODE, SECTION III, DIVISION 5, "HIGH TEMPERATURE REACTORS"

"It endorses, with exceptions and limitations, the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (BPV) Code (ASME Code) Section III, "Rules for Construction of Nuclear Facility Components," Division 5, "High Temperature Reactors"" - DG-1380

- Draft Regulatory Guide (DG-1380) and draft NUREG were issued for public comment (August 2021)

- Final reports expected fall 2022.

NRC Endorsement: Exceptions and Limitations

The NRC is not endorsing:

- HHA-3141, Oxidation: The provisions of HHA-3141(c) that set the weight loss limit as 30% for geometry reduction in the oxidation analysis.
- HHA-3142.4, Graphite Cohesive Life Limit: The provisions of HHA-3142.4 that set the graphite cohesive life limit fluence to the fluence at which the material experiences a +10% linear dimensional change in the with-grain direction.
- HHA-3143, Abrasion and Erosion: The provisions of HHA-3143 that set the mean gas flow velocity limit of 100 meters per second (330 feet per second) for evaluating the effects of erosion on the GCC design.
- HHA-4233.5, Repair of Defects and Flaws: The provisions of HHA-4233.5 that set a maximum allowed repair depth of 2 millimeters (0.079 inch).

Sec. III-5 HAB (General Requirements) Development and Status

- The Society needs to prepare for the first graphite certificate holder applicants.
  - Optimize data report forms to graphite and composite applications.
  - Certify and train Authorize Inspector Agencies on nuclear graphite and composite supply chain activities.
  - Roll-out requirements to the supporting Material Organizations.
- Incorporate recent NRC guidance from DG-1380.
- Extend the graphite code to include an in-service inspection surveillance program.
  - Currently nonexistent although mentioned several places in HAB.
  - Need to explicitly call out Sec. XI Div. 1 and Div. 2, although not directly applicable.

Sec. III-5 HAB Data Report Forms

- Who certifies what ??
- Role of the
  - G Certificate Holder
  - GC Certificate Holder
  - Material Organization (QMO vs CMO)
  - Authorized Inspector (I)
  - Owner (O)

Table HAB-3255-1
Document Distribution for Design and Construction of Core Components and Assemblies

Document	Prepared by	Reviewed by	Certified by	Approved by	Provided to [Note (1)]	Available on Request
Design Specification (HAB-3250)	O	O	O	...	G, GC, I, J	...
Construction Specification (HAB-3340)	G	O	G	O	O, GC, MO	I, J
Design Drawings (HAB-3340)	G	O	G	O	O, GC, MO	I, J
Design Report (HAB-3352)	G	O	G	O	O, GC	I, J
Material Data Sheets (HAB-3353)	G	O	G	...	O	J
Construction procedures (HAB-3451)	GC, MO	G	...	G	G, O	I, J
Certified Material Test Reports	MO, GC	G	MO, GC	...	GC, O	I, J
Shop and field drawings (HAB-3452)	GC, MO	G	...	G	GC	I
Construction Report (HAB-3454)	GC	G,O	G	O	G, O, I	I, J
Data Report Form G-1 (HAB-8410)	GC, G	I	GC, I	...	O, I	J
Data Report Forms G-2 and G-4 (HAB-8410)	GC, MO	I	GC, MO, I	...	GC, I	J
Data Report Form N-3 (HAB-8420)	O	I	O, I	J	...	...

Form G-1

NEW R22-1013 (G-1)

CERTIFICATION OF DESIGN

Design Specification No. ____(18)____ Revision ____
Design Report Number ____(19)____ Revision ____
Construction Specification No. ____(20)____ Revision ____
Construction Report No. ____(21)____ Revision ____

G CERTIFICATE HOLDER'S (Designer) REPORT OF CERTIFICATION

I, the undersigned, representing the Designer and employed by ____ have examined and evaluated the Construction Report for the Graphite or Composite Core Component or Core Assembly described in this Data Report. Following evaluation, the Construction Report has been certified and to the best of my knowledge and belief the GC Certificate Holder has constructed this component in accordance with the rules of the ASME Code, Section III, Division 5, and the construction specification listed herein, and these construction specifications meet the requirement of the Design Specification.

Certificate of Authorization No. ____(22)____ Expires ____
Date ____ Name ____ Signature ____

GC CERTIFICATE HOLDER'S CERTIFICATION OF CONSTRUCTION COMPLIANCE

We certify that the statements made in this report including listed G-2 and G-4 Data Reports are correct and that all details of materials, construction, and workmanship of this Graphite or Composite Core Component or Core Assembly conform to the rules for construction of the ASME Code, Section III, Division 5, and the Construction Specification listed herein.

Certificate of Authorization No. ____ Expires ____
Date ____ Name ____(23)____ Signature ____

CERTIFICATE OF INSPECTION

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure and employed by ____(24)____ have inspected the Graphite or Composite Core Component or Core Assembly described in this D that to the best of my knowledge and belief this component has been constructed in accordance w Section III, Division 5.

By signing this certificate neither the Inspector nor his employer makes any warranty, expressed o the graphite or composite core assembly described in this Data Report. Furthermore, neither the I employer shall be liable in any manner for any personal injury or property damage or a loss of any connected with this inspection.

Certificate of Accreditation No. ____(25)____ Expires ____
Date ____ Signed ____(26)____ Commiss

MACHINING PERFORMED BY

Date ____ Name ____(17)____ Signature ____

NEW R22-1014 (G-2)

CERTIFICATE OF MACHINING COMPLIANCE

We certify that the statements made in this report are correct and that all components listed in t rules for machining of the ASME Code, Section III, Division 5.

GC Certificate Holder
Certificate of Authorization No. ____(19)____ Expires ____
(GC Certificate Holder)
Date ____ Name ____(19)____ Signature ____

CERTIFICATE OF INSPECTION

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Press and employed by ____(20)____
Certificate of Accreditation No. ____(21)____ Expires ____
have reviewed and accept the graphite or composite core component described in this Data Report and state that to the best of my knowledge and belief this component has been machined in accordance with the ASME Code, Section III, Division 5.

By signing this certificate neither the Inspector nor his employer makes any warranty, expressed or implied, concerning the graphite or comp employer shall be lia connected with this i

Date ____

Sec III-A Mandatory App. V

Composites rules integrate with the graphite rules under **Class SN Nonmetallic Core Components.**

Form G-4 Page 2 of ____(1)____

INSTALLED BY

Date ____ Name ____(19)____ Signature ____

CERTIFICATE OF INSTALLATION COMPLIANCE

We certify that the statements made in this report are correct and that the installation of the Graphite or Composite Core Component(s) forming the Graphite or Composite Core Assembly listed in this report conform(s) to the Construction Specification and associated drawings.

NEW R22-1015 (G-4)

GC Certificate Holder
Certificate of Authorization No. ____(2)____ Expires ____
(GC Certificate Holder)
Date ____ Name ____(21)____ Signature ____

CERTIFICATE OF INSPECTION

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and employed by ____(22)____
Certificate of Accreditation No. ____(23)____ Expires ____, have inspected the graphite or composite core component described in this Data Report and state that to the best of my knowledge and belief this component has been constructed in accordance with the ASME Code, Section III, Division 5.

By signing this certificate neither the Inspector nor his employer makes any warranty, expressed or implied, concerning the graphite or composite core assembly described in this Data Report. Furthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

Date ____ Signed ____(24)____ Commission ____(25)____
(AIA)

R21-2225 WG approved; separated into separate records for SC review.

Sec. III-5 HHA (Graphite) Development and Status

- Task Groups
  - Degradation: Planning & Monitoring
  - POF (Weibull & modelling)
  - Oxidation
  - Irradiated Graphite
  - Molten-salt

- Code Changes
  - Material Data Sheets
  - Clarifications

ASME Sec. III on Design & Construction and Sec. XI on In-Service Inspection (ISI) and Reliability & Integrity Management (RIM)

- ASME Strategic Objective to improve the interface between Sec. III & Sec. XI
  - Part of the 2025 Code Cycle Priorities

- Ongoing for metallics, concerns raised for transition from construction to examination are not well aligned

  - Sec. XI Div. 1 evolved exclusively around LWR technology.
  - Sec. XI Div. 2 (RIM), a risk-informed ISI program → initiated to couple with Sec. III for products (advanced reactor designs) not included under Sec. XI Div 1.

- Determining Safety Classification and Categorization using processes consistent with regulation is the responsibility of the Owner
  - This is ASME / US approach but may be different for others (e.g. UK etc.)

Nonmetallic (SN) Criteria Material Degradation, ISI & RIM

- **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."

For Graphite and Composite Materials ASME require

As-Fabricated material properties (unirradiated)

Over operating temperature range

Irradiated material properties

Oxidation effects on material properties

Sec III

Design for nominal plant life using predictive models :

- As-fabricated
- Irradiated
- Oxidation or chemical attack
- Stress-time-temperature

Sec XI

Plan for component surveillance using assessment models:

- Inspection (forewarning of severe cracking)
- Monitoring (deterioration of the graphite and impact on the overall condition)
- Structural Assessment (damage predictions)
- Consequences (Consideration of observed and postulated deterioration of graphite components)

WG-NDM Task Group on Material Degradation & Failure Monitoring

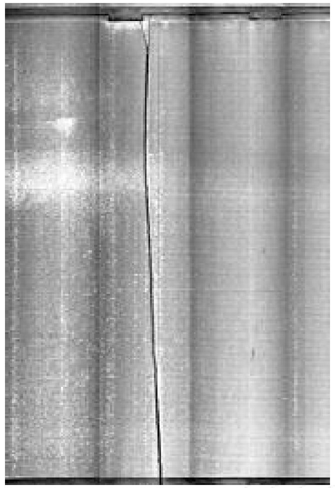
TPOC: Martin Metcalfe

- Only the designer can define what/how a component fails
  - Single crack / multiple cracks / crack in a specific orientation
- Meaning of "failure", "functionality" and "damage tolerance" needs to be unambiguous:
  - Probability of Failure = Probability of Crack Initiation (R22-486 in progress)
  - Damage tolerance levels depend on core design and functionality
  - A crack in the graphite components does not necessarily result in the loss of component function. *Ultimately the loss of function is component failure.*
- Monitoring and surveillance programmes should be an integral part of the core design
- Multi-legged safety cases (inspection, monitoring, assessment, consequences)
- Designers will have to design to some nominal lifetime, but also with some consideration of lifetime margins. Plant operators will certainly wish to plan for economically beneficial life extensions.
- Initial focus on graphite (composites to follow)

❖ Martin Metcalfe, "Damage Tolerance in the Graphite Cores of UK Power Reactors and Implications for New Build" whitepaper in review, publishing NED TBD.

Reliability and Integrity Management (RIM)

- Many of these new rules are not applicable for construction rules (Section III)
- Discussing new rules within Section XI, Division 2 (RIM)
  - **Long term degradation rules**
  - RIM data required to determine failure
    - *RIM data to determine **if failure has occurred***
- End-of-life irradiation and oxidation degradation rules



Cracked AGR core brick at Hunterston B power station

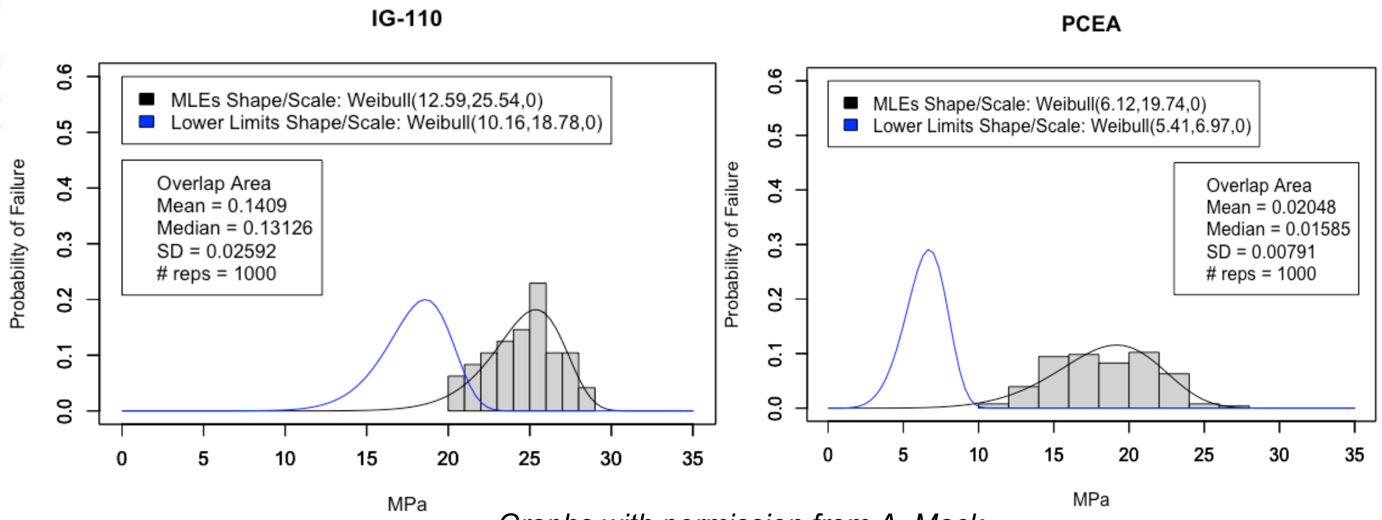
TPOC: Andrea Mack

Graphite workshop (Weibull & POF)
Aug 2022, virtual meeting

WG-NDM Task Group on POF (graphite)

Allowable stress calculation: 3-parameter method

Should the absolute level of uncertainty be controlled?



Graphs with permission from A. Mack

R21-1581 in preparation

Calculation of the process zone parameter, V_m

$$V_m = \left(\frac{\pi}{2} * \left(\frac{K_{IC}}{\sigma_m}\right)^2\right)^3$$

Errata

Stress range parameter, $\Delta = 0.2$

$$V_m = \left(\frac{4\pi}{3} * \left[\frac{r_c}{2}\right]^3\right)$$

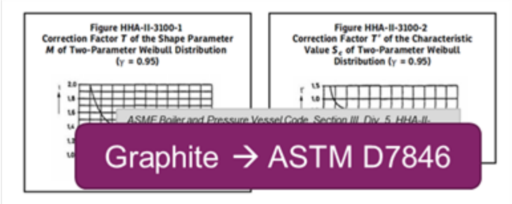
where: $r_c = \frac{1}{2\pi}\left(\frac{K_{IC}}{\sigma_m}\right)^2$

- The code provides a method to always use a conservative stress distribution, but the current process is not a quantifiable conservatism.
- POF without volume grouping is less conservative
  - finer mesh = higher POF (more conservative)
  - Stress range parameter determines volume group size (mesh size), not V_m

Allowable stress calculation: 2-parameter method

Integrate code with ASTM standards

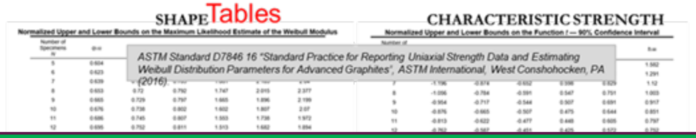
Replace this:



Graphite → ASTM D7846

With this:

Pivotal Quantity Functions: ASTM Tables

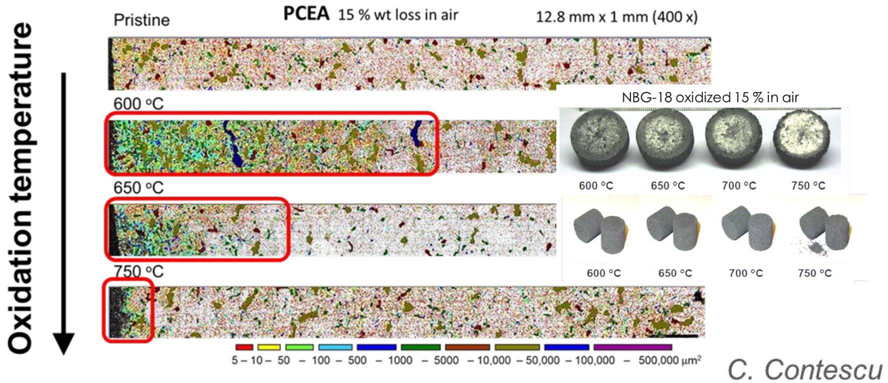


R20-1308 SC approved – On path for 2023 ed.

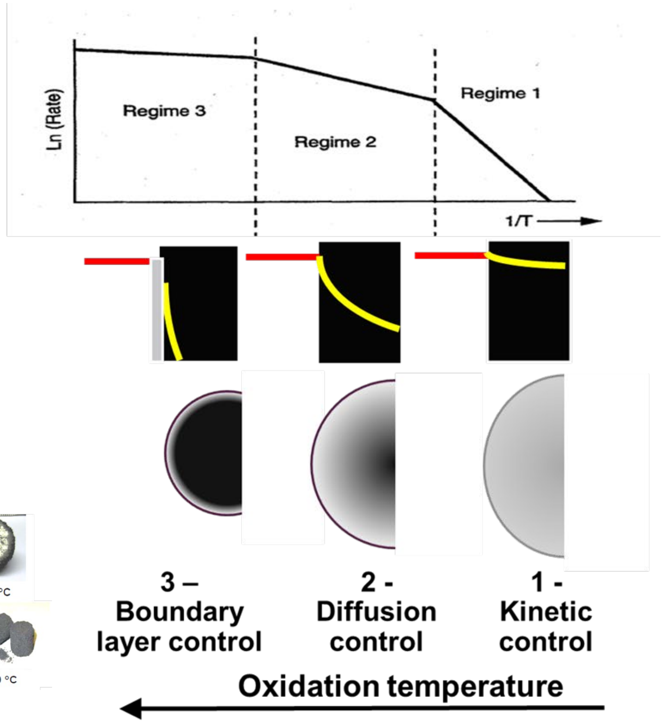
*Tables shown are top 20 rows. ASTM tables go up to sample sizes of 120.

WG-NDM Task Group on the Modification of Oxidation Rules

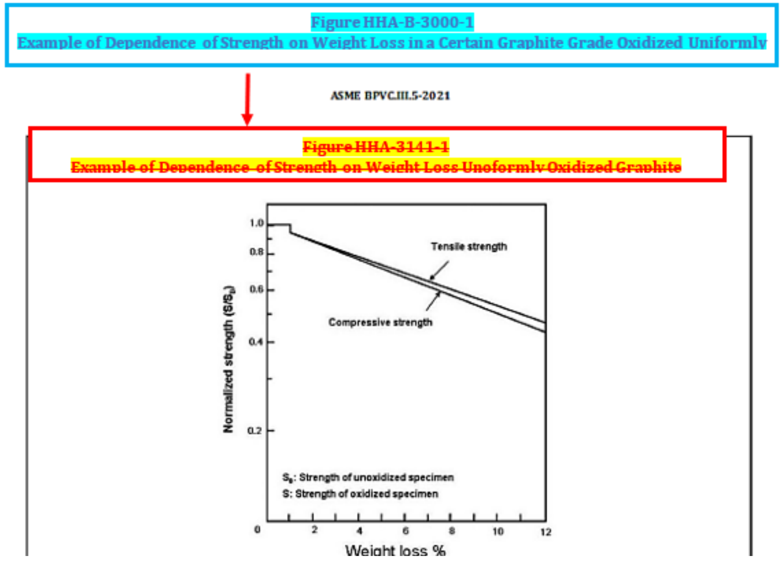
- **Oxidation is local**
  - Irradiation is not local
- **Weight loss is local**
  - Intrinsic factors (microstructure, raw materials, forming method)
  - Extrinsic factors (temperature, oxidant supply, flow conditions, shape and size)



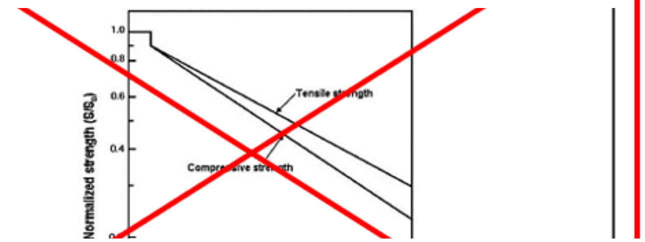
C. Contescu



TPOC:
C. Contescu & R.M. Paul



Numerous results in the literature conclude that the strength of various grades of uniformly oxidized graphite specimens drops to 50 % of initial strength at 10 % weight loss.



R21-1392 SC approved – On path for 2023 ed.

FORM MDS-1 MATERIAL DATA SHEET (SI UNITS)

Property Degradation versus Weight Loss % in Uniformly Oxidized Graphite

Graphite Oxidation – Effect						
Property	Units	2%	4%	6%	8%	10%
Strength [.] (28)						
Elastic modulus (dynamic) [.] (29)						
Thermal conductivity [.] (30)						

- C. Contescu, R.Paul, "Oxidation Behavior and Property Degradation of Nuclear Graphites", ORNL/TM-2022/1839
- Ryan M. Paul et al., "On the Thermal Oxidation of Nuclear Graphite Relevant to High-Temperature Gas Cooled Reactors" whitepaper in progress, publishing TBD.

TPOC: Will Windes

WG-NDM Task Group on Irradiated Graphite

Objective: To revise the code to require an applicant to provide limited irradiation data to ascertain similar behavior (significant cost and time reduction for material qualification).

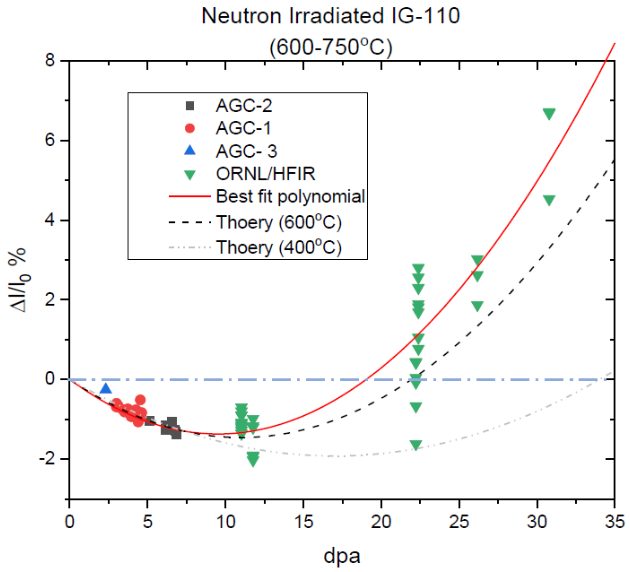
Aim to establish turnaround with only a few data points to (1) confirm data trend and (2) reduce the burden of large irradiation experiments.

Implementing Dimensional Change Theory

$$\frac{dG_x}{d\gamma} = A_x\left(\frac{1}{X_c}\frac{dX_c}{d\gamma}\right) + (1 - A_x)\left(\frac{1}{X_a}\frac{dX_a}{d\gamma}\right) + f_x$$

W. Windes, A. Campbell, S. Johns

- Establish lower bound design constraints (95% lower limit)
- Determine turnaround → tricky due to irradiation experiment temperature control



Effort ongoing: to be repeated with strength, elasticity, CTE and thermal diffusivity

Several whitepapers & code changes expected for 2025 ed.

R19-2810 in progress (Review of irradiation dependent strength increase)

TPOC: Nidia Gallego

WG-NDM Task Group on Molten Salt

Graphite materials workshop
Upcoming July 2022, virtual meeting

- Salt impregnation into graphite pores
  - Physical damage/cracks
  - “Hot spots” from fueled molten salt
- Wear/abrasion/erosion
  - Molten salt has higher density than graphite
  - Liquid flow over soft graphite has potential
- Chemical coupling with metallic systems
  - Graphite – MS is inert but …
  - There are questions when a metallic component is added

Salt residue

After immersion in FLiNaK

Before immersion in FLiNaK

The current HHA does not address any coolant salt interactions with graphite.

Chemical attack, salt infiltration and retention as well as wear and erosion aspects need to be incorporated in the design rules.

2023 Code Changes & Clarifications

When generating irradiated material properties for a Material Data Sheet for a graphite grade, as required in HHA-2200(a) in accordance with the requirements of mandatory appendix HHA-II-4000, **is it permissible to use limited extrapolation** from experimental data with justification to the temperature-fluence envelope of the material data sheet?

***YES**, you can use limited extrapolation of data*

R21-557 approved

- *You can use historical data*
- *Must prove that it is **same grade***

R22-208 approved

ARTICLE HHA-III-5000
USE OF HISTORICAL DATA

This Appendix does not require new testing if the required test data are already generated. The historical data shall meet the requirements of this Appendix and be on the same graphite grade. If credit is taken from previous qualification programs, then testing shall also demonstrate that the historic data is applicable to the current production material.

Clarified the minimum number of test samples required to qualify a graphite grade

R22-309 approved

ARTICLE HHA-III-4000
…EMENT FOR REPRESENTATIVE DATA

HHA-III-4100 AS-MANUFACTURED GRAPHITE

As-manufactured material property data shall be obtained from at least three charges, consisting of a minimum of four billets per charge, of material meeting all of the requirements of the material specification (see Mandatory Appendix HHA-I). Moreover, property data (including the effects of temperature on properties) shall be obtained from billets whose dimensions are comparable to the production billets for which a Material Data Sheet is to be prepared. Specimen sampling plans and billet selections shall reflect the anticipated heterogeneity of the product form. The requirements for sampling are based on the material forming method as follows:

(a) *For Extruded Material:* Measure two specimens in both the with-grain and against-grain direction from both

first bake. Slices shall be selected so th… proximately equal numbers of slices fron… and bottom over all of the billets that a… the Material Data Sheet.

(c) *For Isomolded Material:* Measure t… both the with-grain and against-grain dir… the center and periphery of a slice taker… The slices shall be taken from the top, mi… of the billet relative to the orientation of… first bake. Slices shall be selected so th… proximately equal numbers of slices fron… and bottom over all of the billets that a… the Material Data Sheet.

The measurements described in (a) th… are minimum values. More specimens m… It is not permissible to replace additiona…

Clarified the definition of G and GC Certificate holders in code rules

R21-1581 in review by Sec III

G Certificate Holder: the organization assuming responsibility for Code compliance with respect to design of Core Components or Core Assemblies.

GC Certificate Holder: the organization assuming responsibility for Code compliance with respect to material, manufacture, installation, examination, testing, inspection, and certification of Core Components or Core Assemblies in accordance with the Design Drawings and Construction Specification.

2023 Code Changes – ASME Materials Data Sheets (HHA-II)

- Elevated temperature testing
  - Graphite gets stronger with increasing temperature
  - Very difficult to test:
    - *No test standards*
  - Very little advantage
    - *Modulus increases*

- ***This is optional***
  - *Since strength increases with temperature, if elevated temperature strength* ***is not used*** *then considered conservative.*

FORM MDS-1 MATERIAL DATA SHEET (SI UNITS)

Grade Designation

Material Grade ________ Material spec. ID ________ ASTM spec. ________

Max. grain size (mm) ________ Designation ________

Temperature-Dependent Parameters

Property	Units	Orientation	20°C	200°C	400°C	600°C	800°C	1000°C [Note (1)]
Bulk density	kg•m⁻³	...						
Strength – tensile	MPa	WG, AG						
Strength – flexural (4-point)	MPa	WG, AG						
Strength – compressive	MPa	WG, AG						
Elastic modulus (dynamic)	GPa	WG, AG						
Elastic modulus (static)	GPa	WG, AG						
Coefficient of thermal expansion	°C⁻¹	WG, AG						
Thermal conductivity	W/m•k	WG, AG						

R19-2806 under review for first iteration ballot at Sec. III

Future Code Changes

Graphite Oxidation – Effect						
Property	Units	2%	4%	6%	8%	10%
Strength [.]						
Elastic modulus (dynamic) [.]						
Thermal conductivity [.]						

Irradiated Graphite			
Property	Units	WG	AG
Dimensional change [.]			
Creep coefficient [.]			

- *Material property after oxidation*
  - **Must be** performed at lowest temperature possible.
  - Maximum oxygen penetration and maximum effect on material properties
- *Irradiation effects*
  - Behavior should be represented as plots dependent upon received dose and irradiation temperature
  - Writing code rules to establish a universal response for all grades of graphite

Sec III-5 HHB (Composites) Development and Status

- Code Changes
  - Loading mode stress
  - Non-mandatory appendices

- Task Group
  - Composites (Technical Basis and Benchmarking)
  - Synergies

  - Future:
    - POF
    - Degradation: Planning and Monitoring

2023 Code Changes – Failure Mode Stress (Composites)

Graphite | **Composites**

Technical Requirements

Graphite Core Components	Composite Core Components
HHA	HHB
Graphite Core Assembly	CMC Components
Maximum deformation energy theory (equivalent stress)	Failure Mode Stress Theory (equivalent stress do not apply)
- Design by Analysis - Simple assessment - Full assessment - Design by test	- 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) ______

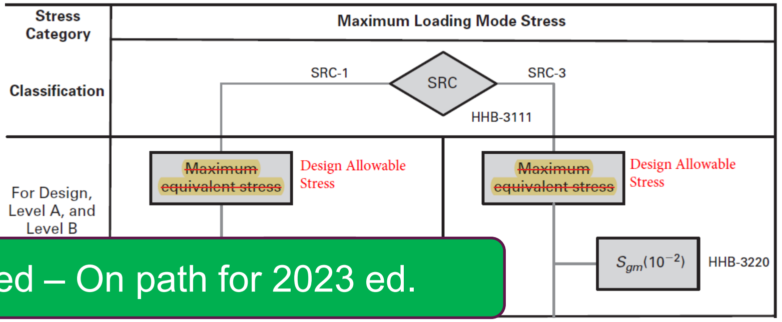
~~Ratio of flexure to tensile strength, R_{tf}~~ (27b) ______

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



R21-728 HHB Corrections SC approved – On path for 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)

- <u>HHA Simple Assessment</u>: calculate the peak equivalent stress
- <u>HHA Full Assessment</u>: 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 <u>does not make use of the theory for combining stresses</u>. The stress at failure needs to be determined for the mode at failure exercised by the applied stress. (HHB—3213)

- <u>HHB Simple assessment</u>: calculate the maximum loading mode stress

The equivalent stress approach should not be used in HHB.

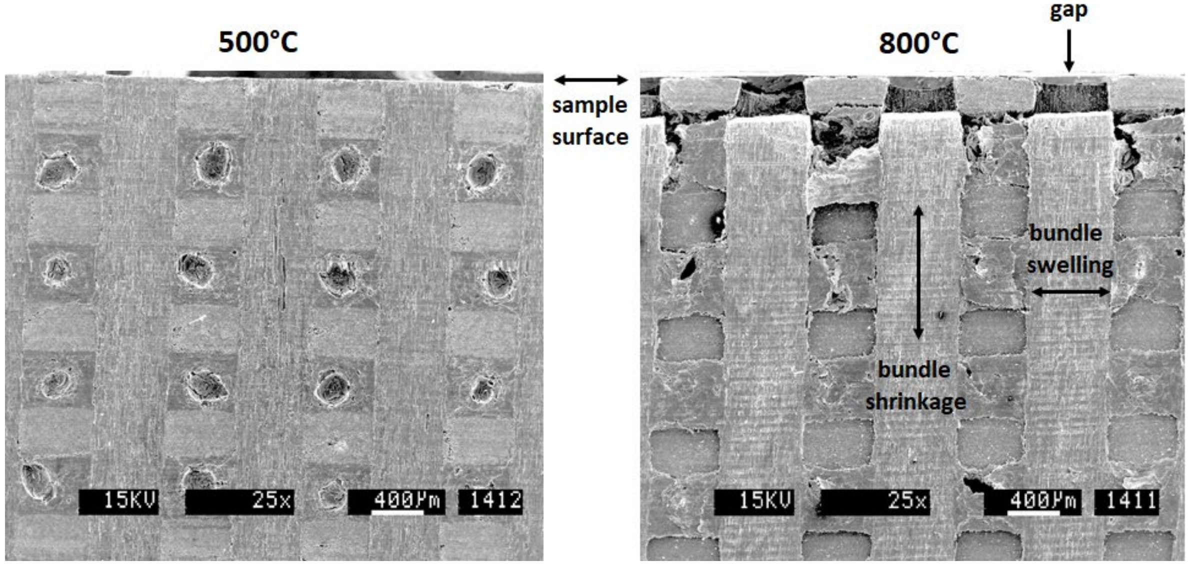
The ratio of strengths is not applicable to composites

HHB C-C CMC Non-mandatory Appendices

HHB-D C-C Materials and Applications
HHB-E C-C Irradiation and Environmental Effects

CMC Irradiation and Environmental Effects

Campbell Anne A. and Burchell Timothy D. (2020). Radiation Effects in Graphite. In: Konings, Rudy JM and Stoller Roger E (eds.) Comprehensive Nuclear Materials 2nd edition, vol. 3, pp. 398–436. Oxford: Elsevier.



C-C composite following irradiation (at 500°C and 800°C)

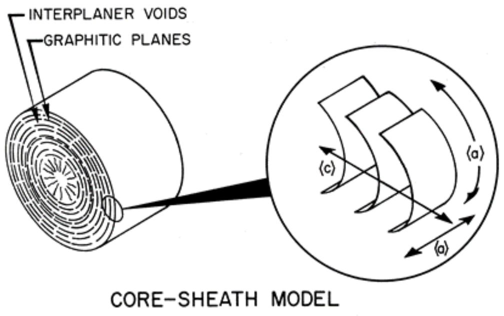
L.L. Snead et al. / Journal of Nuclear Materials 321 (2003) 165–169

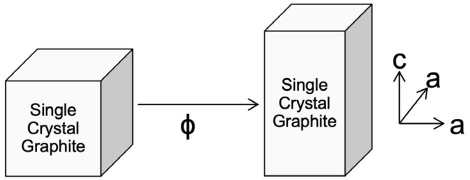
L. Snead, Ceramic structural composites: The most advanced structural material, presented at the International School on Fusion Reactor Technology, Erice, Italy, July 26–August 1, 2004.

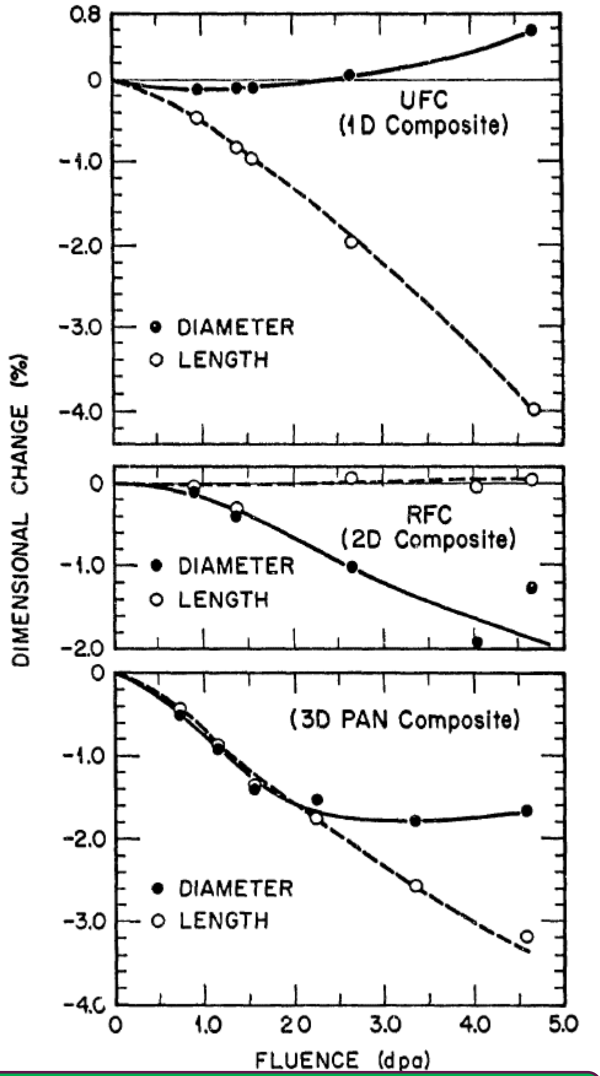
T.D. Burchell, Radiation damage in carbon-carbon composites: Structure and property effects, Physica Scripta 64, 17–25, 1996.

T.D. Burchell., Irradiation-induced Structure and Property Changes in Tokamak Plasma-facing, Carbon-Carbon Composites, Moving Forward with 50 Years of Leadership in Advanced Materials, 39th International SAMPLE Symposium and Exhibition, vol. 39, Books 1 and 2, pp. 2423–2436, 1994.

T.D. Burchell, T. Oku, Materials Properties Data for Fusion Reactor Plasma Facing Carbon-Carbon Composites, International Atomic Energy Agency, pp. 77–128, 1994.







R20-1307 (HHB-D & HHB-E) SC reviewed – On path for 2023 ed.

TPOC: Josina Geringer

WG-NDM: Task Group on Composites

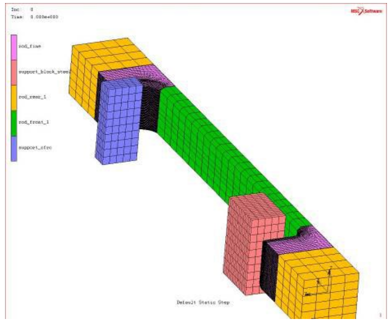
The composites task group is a subset of the nonmetallic design and materials working group (NDM-WG) with specific focus to address mission relevant activities as it relates to Sec III.5 HAB and HHB on ceramic matrix composites.

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.

Monthly occurrence

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 practicability and readiness
  - Identify optimization areas.

TPOC: Josina Geringer

WG-NDM Task Group on Composites

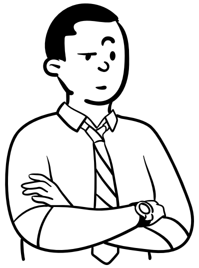
HHB-3214.7 Combined Stress (C_m + C_b). The combined stress is the sum of all of the components of stress at a point. In design, it is customary to distinguish between primary and secondary stresses. These are defined as follows:

(a) Primary stress is any normal stress or a shear stress developed by an imposed loading that is necessary to satisfy the laws of equilibrium of external and internal forces and moments. The basic characteristic of a primary stress is that it is not self-limiting. Primary stresses that considerably exceed the material strength will result in failure. A thermal stress is not classified as a primary stress.

(b) Secondary stress is a normal stress or a shear stress developed by the constraint of adjacent material or by self-constraint of the structure. The basic characteristic of a secondary stress is that it is self-limiting. Local yielding and min...
cause the st...
Due to th...
distinction...
stresses for...
Combined...
stress and s...

For composite materials, matrix failure modes are not always catastrophic.

- *How is this applied elsewhere?*
- *What does NASA and FAA apply?*



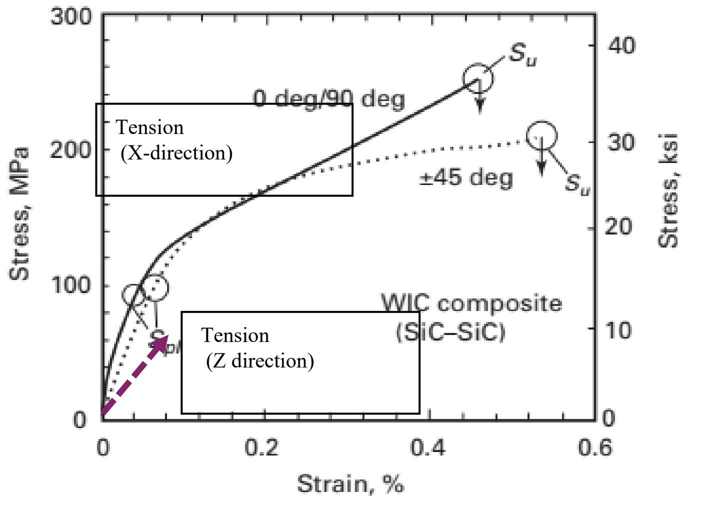
Could a higher POF be applied to interlaminar stresses if they:

- *Are self-relieving / self-limiting?;*
- *Do not induce fiber-dominated failure? and;*
- *Do not compromise the component's ability to function?*

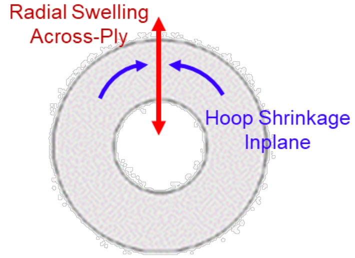
HHB-3214.2 Maximum Loading Mode Stress. The maximum loading mode stress in a Composite Core Component is the highest loading mode stress computed from the total str...
cordance wi...
This stres...
of the loads i...
maximum lo...
most severe...
loadings or ...
vice Level.

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

Figure HHB-II-3300-1
Stress–Strain Curves for WIC Composites

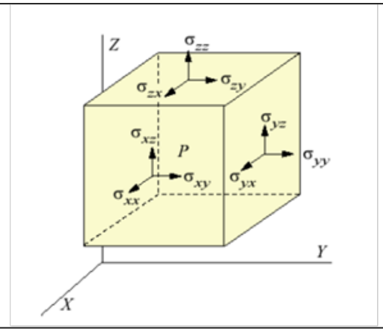


Internal Stresses due to Irradiation



Hoop direction develops tensile stress
Radial direction develops compressive stress

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)



CMC Synergistic Activities & Industry Alignment

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)

CMH-17

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**
- Chapter 14 – Subcomponent Testing – Overvi
- Chapter 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

ASTM INTERNATIONAL
Helping our world work better

	Units	ASTM Test – Flats-Bars	ASTM Test – 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/m^3	C1275, C1359	C1773
Modulus of Toughness (in Tension)	J/m^3	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/m^2	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

From minutes of C28.07 meeting on Jan 31, 2022.

Code Week Meetings

Development of the design ASME BPV code for graphite and ceramic composite core components were discussed and coordinated at several ASME hosted virtually or in-person during 2021 and 2022.

Meeting Date	Organization: committees	Location
25-30 Jul 2021	ASME: WG GR GCCCCA, WG-NDM, SG-HTR, BPVIII	Virtual (Zoom), NY
1-4 Nov 2021	ASME: WG GR GCCCCA, WG-NDM, SG-HTR, BPVIII	Virtual (Zoom), NY
6-11 Feb 2022	ASME: WG GR GCCCCA, WG-NDM, SG-HTR, BPVIII	Virtual (Zoom), NY
1-5 May 2022	ASME: WG GR GCCCCA, WG-NDM, SG-HTR, BPVIII	New Orleans, LA
7-12 Aug 2022	ASME: WG GR GCCCCA, WG-NDM, SG-HTR, BPVIII	Virtual (Zoom), NY
5-12 Nov 2022	ASME: WG GR GCCCCA, WG-NDM, SG-HTR, BPVIII	Pittsburg, PA

Workshops associated with respective Task Groups planned:

- Molten Salt Workshop (July 2022)
- Weibull Graphite Experts (August 2022)

Virtual meeting in August and in person meeting in November (Pittsburg)

Foreseeable future two in-person and two virtual meetings per year.

Questions?