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Report on the ASME design code development effort for Composite Core Components for High Temperature Reactors

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OAK RIDGE NATIONAL LABORATORY
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SiC/SiC Composite Design Rules

Report on the ASME design code development effort for Composite Core Components for High Temperature Reactors

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CONTENTS

FIGURES

TABLES

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ABSTRACT

This report summarizes the activities and status of the ASME design code development effort for Composite Core Components for High Temperature Reactors during Fiscal Year 2018. The subsection drafts develop for ASME BPVC Division 5 Section III, namely Subsection HA Subpart B and Subsection HH Subpart B, are near publication.

It is likely that Subsection HH Subpart B will be accepted during the next ASME review meeting. Subsection HA Subpart B may have to continue through more review iterations before final acceptance. Two new standards for fiber-reinforced advanced ceramic composites have been published and a report on the technology gap for Molten Salt Reactor applications of SiC/SiC composites was completed.

ACKNOWLEDGEMENTS

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1. INTRODUCTION

ASME BPVC Section III is developing design rules for composite core components in high temperature nuclear reactors. The code aims to address the construction requirements for nuclear reactor application of SiC-SiC and Carbon-Carbon matrix composite materials.

The composite code development work is undertaken by three Working Groups on Graphite and Composite Materials (WG GCM), Graphite and Composite Design (WG GCD) and General Requirements for Graphite and Ceramic Composite Core Components and Assemblies (WG GR GCCCCA) within *ASME BPVC Section III (Nuclear), Division 5 (High Temperature Reactors).* Standards developed under ASTM C28.07 have been adopted to support the ASME code development.

During this fiscal period a study was also conducted to evaluate the technology gap for Molten Salt Reactor (MSR) designs.

ORNL is responsible for chairing most of the ASME Working Groups as well as the ASTM chapter.

Test standards are developed to standardize the test methods and guidelines for composites, in this case testing for classifications, mechanical, thermal and other (e.g. oxidation) properties. Activities include round-robin testing to develop test statistics and precision statements.

Key highlights for the reporting period are:

- Completion of the report on SiC-SiC Composites Technology Gap Analysis for Molten Salt Reactors [1].
- Articles for Sub-Section HH Sub-part B are issued to BPV III. Record 17-2659 has been circulated through three ballot reviews. It is pending BPV III committee approval.
- A new Working Group on the General Requirements for Graphite Components and Core Composite Components and Assemblies was formed within ASME BPV III. Articles under Sec III Div 5 Sub Sect. HA Sub-Part B were revised and passed Working Group and Sub-Group reviews. It is pending BPV III ballot approval.
- Three talks were presented at ANS and NSMMS. The details are shown later.
- Two new ASTM standards on fiber-reinforced advanced ceramic composites were published. Additionally, there are three new ASTM standards in review and three new standards in draft. The details are shown later.

The main contributors for this work include:
Dr. Y. Katoh (Program Lead), J.W. Geringer (Program Coordinator and WG-GCCR Secretary), Dr. T.D. Burchell (Author and WG-GCM Chair), M.M. Mitchell (Author and WG-GCD Chair), Dr. S.T. Gonczy (Author), Dr. M.G. Jenkins (Author) and A.A. Wereszczak (C28.07 Chair).

2. PROGRESS STATEMENT

2.1 ASME CODE DEVELOPMENT

The work completed during FY18 include the generation and revision of the two consolidated drafts on technical and general requirements namely, Subsection HH Subpart B and Subsection HA Subpart A for the ASME Section III Division V code for Composite Core Components. This provides for composite core components for High Temperature Reactors, specifically targeting High-temperature Gas Cooled and Molten Salt type reactors. The code as written is directly applicable to High Temperature gas-cooled rectors and will be extended to molten salt reactors as the specific applications are better defined.

The code needs to be assessed to ensure it makes adequate provision for effects more prominent in MSR's like thermal striping and flow induced vibrations. Further investigation is required to understand the fission product interaction and the effects on the structural material which is relevant to liquid fueled MSR designs.

Technical Requirements:
The draft code is published on ASME C&S Connect a record No. 17-2659: *BPVC, Section III, Division 5, Sub-section HH, Class SN Nonmetallic Core Components, Subpart B, Composite Materials.* This document is substantially complete and comprises the following articles and appendices:

- HHB-1000: Introduction
- HHB-2000: Materials
- HHB-3000: Design
- HHB-4000: Machining and installation
- HHB-5000: Examination
- HHB-6000: Testing
- HHB-8000 Nameplates, Stamping and reports
- Appendix HHB-A
- Appendix HHB-B
- Appendix HHB-C
- Appendix HHB-I
- Appendix HHB-II
- Appendix HHB-III

The codes are on ballot for approval at the BPV III Standards committee. It is on a second recirculation ballot. The history of the review is summarized below:

- Ballot 17-3386, Closed 01/10/18 (15 approved, 8 disapproved, 2 abstentions, 1 not voting and 7 not returned)
- 17-3386RC1, Closed 05/01/18 (19 approved, 5 disapproved, 3 abstentions, 1 not voting and 6 not returned)
- 17-3386RC101, Circulated in error.
- 17-3386RC102 Opened 07/10/18 – In Progress. (status at time of report: 23 approve).

The chart in Figure 1 summarizes the current ballot progress.

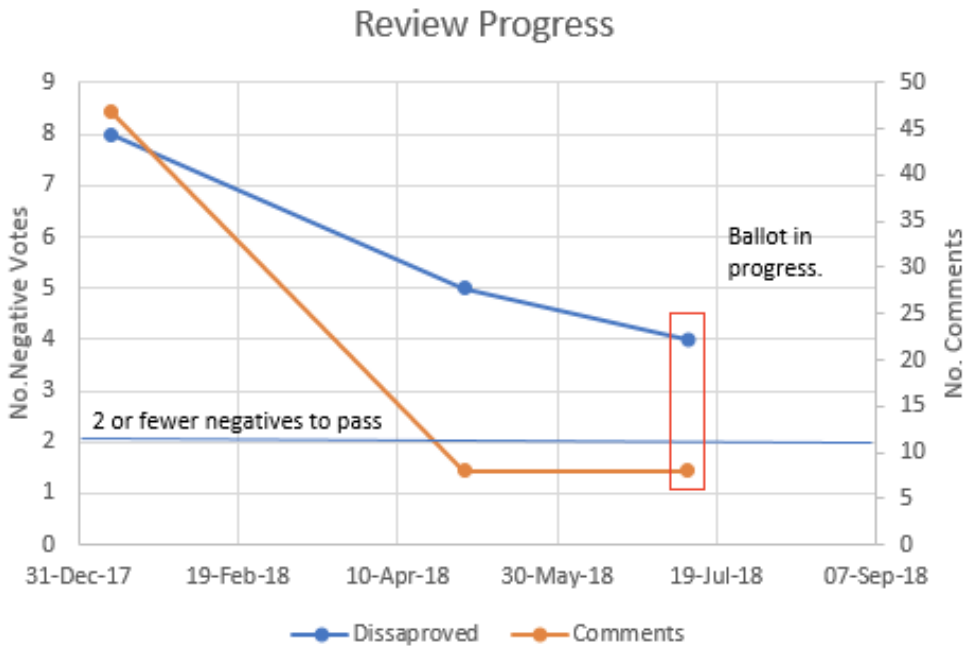

Figure 1: Current balloting progress of record No. 17-2659 - BPVC, Section III, Division 5, Sub-section HH, Class SN Nonmetallic Core Components, Subpart B, Composite Materials

Note that the ballot will approve with two or less negatives. The project team has responded to and addressed all the negative comments provided by the BPV III Committee in the last review cycle. This ballot round will close before the August code week.

General Requirements:

The project team has also generated the first draft administrative or general requirements for the composite core components. The strategy based on direction from the BPV III standards committee was to incorporate these requirements into the existing general requirements for graphite core assemblies and core components.

The project team has prepared record 18-778: *BPVC, Section III, Division 5, Subsection HA Subpart B - General Requirements - Graphite Materials*.

This record has passed subcommittee ballots and has been formally balloted to the BPV III consensus committee. The ballot No was 18-1843. The result of the ballot was: 18 approved, 3 disapproved, 2 abstentions, 0 not voting and 11 not returned.

The project team will address the negative ballots and review the item in the august code week. The aim is to offer the item for second consideration at BPV III after the negatives and comments are addressed.

The code has been developed but is lacking benchmark data and requires validation.

2.2 ASTM C28.07 DEVELOPMENT AND CODE SUPPORT

This section summarizes the progress on the standards development progress under ASTM C28.07 in support of ASME code development activities.

New standards published during FY18:
- ASTM C1869 – 18 – Standard Test Method for Open Hole Tensile Strength of Fiber-Reinforced Advanced Ceramic Composites (Gonczy)
- ASTM C1863 – Standard Test Method for Hoop Tensile Strength of Continuous Fiber-Reinforced Advanced Ceramic Composite Tubular Test Specimens at Ambient Temperature Using Direct Pressurization (Jenkins)

Previous standards published:
- ASTM C1783 – Standard Guide for the Development of Specifications for Fiber Reinforced Carbon-Carbon Composite Structures for Nuclear Applications (Gonczy)
- ASTM C1793 – Standard Guide for the Development of Specifications for Fiber Reinforced Silicon Carbide-Silicon Carbide Composite Structures for Nuclear Applications (Gonczy)
- ASTM C1835-- Standard Classification for Fiber Reinforced Silicon Carbide-Silicon Carbide (SiC-SiC) Composite Structures (Gonczy)
- ASTM C1836 -- Standard Classification for Fiber Carbon-Carbon Composite Structures (Gonczy)
- ASTM C1773 -- Standard Test Method for Monotonic Axial Tensile Behavior of Continuous Fiber-Reinforced Advanced Ceramic Tubular Test Specimens at Ambient Temperature (Gonczy and Jenkins)
- ASTM C1819 – Standard Test Method for Hoop Tensile Strength of Continuous Fiber-Reinforced Advanced Ceramic Composite Tubular Test Specimens at Ambient Temperature Using Elastomeric Inserts (Jenkins)

New standards in review:
- Oxidation Exposure Testing of Ceramics for Retained Properties (Gonczy)
- Torsion Shear Strength of Adhesive Bonding in CMCs at Ambient Temperature (Gonczy)
- Flexural Strength of CMC Tubes at Ambient Temperature (Jenkins)

New standards being developed (in draft):
- Acoustic Emission (AE) Testing for CMC (Jenkins)
- Interlaminar Crack Growth Resistance Testing of CMCs – G_{Ic} and G_{IIc} (Gonzy)
- Compressive Strength of CMC Tubular Test Specimens at Ambient Temperature (Jenkins)

2.3 MEETINGS AND PRESENTATIONS

2.3.1 Meetings

Development of the ASME BPV design code and ASTM standards for ceramic composite core components were discussed and coordinated at several ASME and ASTM meetings that were held during FY18 as shown in Table 1.

Table 1: Summary of official meetings that were held during FY18.

Meeting Date	Organization	Location
Oct 29 – Nov 3, 2017	ASME	Phoenix, AZ
Jan 21, 2018	ASTM	Daytona Beach, FL
Feb 4-9, 2018	ASME	Las Vegas, NV
May 6-11, 2018	ASME	Dallas, TX
Jul 18, 2018	ASTM	WEBEX Meeting
Jul 29 - Aug 2, 2018	ASME	Washington, DC

2.3.2 Presentations

At the American Nuclear Society Annual Meeting, Philadelphia, PA June 17-21, 2018

Y. Katoh, T. Koyanagi, X. Hu, G. Singh, K.A. Terrani, J.W. Geringer, A.L. Qualls, Y. Lee, S. Raiman (ORNL), L.L. Snead (SUNY/SBU), B.D. Wirth (UTK), C. Deck (GA), P. Xu (WEC), C. Sauder (CEA), S. Gonczy(GMT), M. Jenkins (CSU Fresno), "Recent Development in SiC Composite Technologies for Nuclear Energy Applications"

Yoonjo Lee, Yutai Katoh, Takaaki Koyanagi, Lauren Garrison, Wilna Geringer (ORNL), "A Survey: The Chemical Compatibility of Silicon Carbine with Molten Fluoride Salts"

At the National Space and Missile Materials Symposium, Madison WI, June 25-28, 2018

Stephen T Gonczy (Gateway Materials), Yutai Katoh, Wilna Geringer (ORNL), "A New ASTM Test Standard for the Open Hole Tensile (OHT) Strength of Fiber-Reinforced Ceramic Matrix Composites"

2.4 CONCLUSION AND FY19 PLANS

Code development through FY18 in WG-GCM, WG- GCD, WG-GR GCCCCA and ASTM C28.07 made good progress through FY18. Both drafts, *BPVC, Section III, Division 5, Sub-section HH, Class SN Nonmetallic Core Components, Subpart B, Composite Materials,* and the revised, *BPVC, Section III, Division 5, Subsection HA Subpart B - General Requirements - Graphite Materials.,* are near publication and are pending final approval from BPV III committee. Additionally, two new ASTM standards on open hole tensile strength and hoop tensile strength have been published.

Continued activities for FY19 include:

- Continue ASME “Composite Code” committee chairing and secretarial activities for WG-GCM, WG-GCD and WG-GR GCCCCA addressing committee review questions and comments to ensure publication.
- Verify the technical basis of the code with benchmark data and address lacking issues identified during the gap analysis activities for the Molten Salt Reactor technology.
- Complete, ballot, revise, and publish the current ASTM test standard drafts.

During FY18 both code and standard development activities received a lot of interest from the Molten Salt Reactor (MSR) community as well as the Light Water Reactor (LWR) Enhanced Accident Tolerance Fuel Cladding community. There is a definite leverage opportunity on SiC-SiC composite tubes for LWR fuel cladding and certain MSR component development.

3. REFERENCES

[1] Josina W. Geringer, Takaaki Koyanagi, Yoonjo Lee, Yutai Katoh, *SiC/SiC Composites Technology Gap Analysis for Molten Salt Reactors*, ORNL/TM-2018/842, Oak Ridge National Laboratory, June 2018.