PROGRESS OF CODES AND STANDARDS DEVELOPMENT FOR NUCLEAR APPLICATIONS OF CERAMIC COMPOSITE MATERIALS

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ABSTRACT

Ceramic matrix composites, mainly continuous silicon carbide (SiC) fiber-reinforced SiC matrix composites (SiC-SiC composites) and continuous carbon fiber-reinforced carbon matrix composites (C-C or carbon-carbon composites), are currently being evaluated for use at high temperatures and high radiation fields in various advanced high temperature reactor concepts. These composites have a number of desirable properties for high temperature nuclear applications, including excellent thermal and mechanical properties and reasonable (C-C) to outstanding (SiC-SiC) radiation resistance. Moreover, these composites are finding expanding utilization as the fabrication and application technologies mature. However, designing nuclear reactor core components with these composite materials and qualification of certain composite materials for use in nuclear reactors requires the design rules. In order to establish such rules, a development task for rules for the construction of the ceramic composite materials for use in high temperature reactors has been undertaken in the American Society of Mechanical Engineers (ASME), Boiler and Pressure Vessel (B&PV) Code, Section III (Nuclear), Division 5 (High Temperature Reactors), Working Group on Graphite and Composite Design (WG-GCD). The status of the ceramic composite design rules development in the WG-GCD during FY-201D is briefly summarized in this report.

1. Introduction

Ceramic matrix composites, in particular continuous silicon carbide (SiC) fiber-reinforced SiC matrix composites (SiC-SiC composites) and continuous carbon fiber-reinforced carbon matrix composites (C-C or carbon-carbon composites), are currently being evaluated for use at high temperatures and high radiation fields in advanced high temperature reactor (HTR) concepts, including high temperature gas-cooled reactor (HTGR), very high temperature reactor (VHTR), gas fast reactor (GFR), sodium fast reactor (SFR), and fluoride salt-cooled high temperature reactor (FHR). These composites have many desirable properties for high temperature nuclear applications, including excellent thermal and mechanical properties and reasonable (C-C) to outstanding (SiC-SiC) radiation resistance. Moreover, these composites are finding expanding commercial non-nuclear utilization as the fabrication and application technologies mature.

At the beginning of FY-2010, the American Society of Mechanical Engineers (ASME), Boiler and Pressure Vessel (B&PV) Code, Section III (Nuclear), Division 5 (High Temperature Reactors), Sub Group on Graphite Core Components (SG-GCC), initiated the task of writing rules for the construction of high temperature composites components for use in HTRs in support of the Department of Energy (DOE)'s VHTR Composite Program. The experiences and intellectual resources of SG-GCC were determined to be ideal for new design code development for the non-metallic and non-pressure boundary component, since the SG-GCC have developed new code sections for both graphite "General Requirements" and "Design and Construction Rules" for the use of graphite components in the cores of HTR over the period of the past several years. The composite design code development activity has been continued through a programmatic transition at DOE from the VHTR Composite Program to the Advanced Small Modular Reactors (SMR) Research and Development (R&D) Program. Due to re-structuring of the ASME code committees, the composite code development work is presently undertaken by the Working Group on Graphite and Composite Design (WG-GCD) under Subcommittee Design (R2) and the Task Group on Graphite and Composite Materials (TG-GCM) under Subgroup Materials, Fabrication and Examination (R2). The current ASME Section III structure is provided in Appendix A.

Below reported are progress and current status of the development of an ASME approved design code for high temperature ceramic composites for use in HTRs.

2. Progress and status

The ASME WG-GCD has held several meetings during the current FY and discussed development of the design code for ceramic composite core components for high temperature reactors along with the regular committee business on graphite materials for high temperature reactors. These meetings were held within the ASME Boiler and Pressure Vessel Code Meeting weeks. The meetings were thus held as below.

Table 1. ASME WG-GCD meetings held during FY-2014.

Meeting Dates	Meeting Location
October 28-30, 2013	Atlanta, Georgia
February 10-12, 2014	San Diego, California
May 12-14, 2014	Bellevue, Washington
August 18-20, 2014	Washington, D.C.

Over the course of these meetings, a group of engineers and scientists have volunteered and/or been subcontracted to serve as members of WG-GCD and develop the new code rules for composite materials for high temperature reactors.

The new high temperature composites code will comprise two sections, designated subsection HAC General Requirements, and subsection HHB Design Rules for Composites. These two subsections will be ultimately published in sections HA and HH, respectively of the new Division 5 (High Temperature Reactors) of the Boiler and Pressure Vessel Section III Code. Development activity during the current FY focused on the subsection HHB Design Rules for Ceramic Composites. The subsection will consist of the following articles.

Table 2. Currently discussed contents and development status of Subsection HH, Subpart B, Design Rules for Ceramic Composites.

Article	Status
Article HHB-1000 Introduction	2nd version balloted (Appendix B)
Article HHB-2000 Ceramic Composite Materials	2nd version balloted (Appendix C)
Article HHB-3000 Ceramic Composite Design	2nd version balloted (Appendix D)
Article HHB-4000 Machining and Installation	1st version balloted (Appendix E)
Article HHB-5000 Examination	1st version balloted (Appendix F)
Article HHB-6000 Testing	1st version balloted (Appendix G)
Article HHB-8000 Nameplates, Stamping, and Reports	To be drafted.
Mandatory Appendices (Supporting Articles HHB-2000 and 3000)	
Appendix HHB-I – Ceramic Composite Material Specifications – C-C and SiC-SiC	4th revision of C-C and 3rd revision of SiC-SiC being balloted in both ASTM C28 and ASME WG (Appendix H)
Appendix HHB-II – C-C and SiC-SiC Composite Material Data Sheets	1st revision going into 2nd ASME WG ballot (Appendix I)
Appendix HHB-III – Requirements for Generation of Design Data for C-C and SiC-SiC Composites	Being drafted
Non Mandatory Appendices (Supporting Articles HHB-2000 and 3000)	
Appendix HHB-A – Composition, Structure, Manufacture, and Properties of SiC-SiC CMCs	Being drafted
Appendix HHB-B – Effects of Fast Neutron Irradiation on C-C and SiC-SiC Composites	To be developed for C-C. Document for SiC-SiC irradiation effects that will be supplemented has been published (Appendix J)
Appendix HHB-C – Effects of Oxidation on C-C and SiC-SiC Composites	To be developed
Appendix HHB-D – Fracture and Damage Mechanisms in SiC-SiC CMCs	Being drafted
Appendix HHB-E – Guidance on Defects and Flaws in C-C and SiC-SiC Composites	To be developed