Current Status of the Elevated Temperature Structure Design Codes for VHTR

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1. Introduction

An elevated temperature structure design and analysis is one of the key issues in the VHTR (Very High Temperature Reactor) project to achieve an economic production of hydrogen which will be an essential energy source for the near future. Since the operating temperature of a VHTR is above 850°C, the existing code and standards are insufficient for a high temperature structure design. Thus the issues concerning a material selection and behaviors are being studied for the main structural components of a VHTR in leading countries such as US, France, UK, and Japan. In this study, the current status of the ASME code, French RCC-MR, UK R5, and Japanese code were investigated and the necessary R&D items were discussed.

2. ASME B&PV Codes

In the US, class 1 components of nuclear reactor systems are designed per the ASME B&PV Code Subsection NB of which the allowable temperatures are 371°C for ferritic steels and 427°C for austenitic stainless steels. When compared to the conventional nuclear power plants, HTGR and FBR can experience elevated temperatures above the creep regime. Since ASME proposed Code Case 1331 for the elevated temperature structure design in 1967, it has been revised several times and finally upgraded to Subsection NH[1] in 1995. The listed material and corresponding temperature limits are shown in Table 1. The candidate materials for the reactor vessel and the internal structures of VHTR are Mod9Cr-1Mo and Alloy 800H respectively. The ASME-NH is the most widely used design code throughout the world and it has influenced other nation's design codes. The main features of the ASME-NH are described in Table 2.

Table 1. Materials and Temperature Limits

	ASME-NH	RCC-MR	Japan	UK
304SS	800ºC	650ºC		-
316SS	800ºC	650ºC		-
2.25Cr-1Mo	650ºC	550ºC	550ºC	-
Mod9Cr-1Mo	650ºC	600ºC		-
Alloy 800H	750ºC	600ºC		-
SUS321			650ºC	-
Hastelloy XR			1000ºC	-
Alloy 617 (CC)	980ºC *			-

A draft code case for Alloy 617[2], which is a candidate material for the high temperature internal structures and piping, allows its use up to 980°C with a limited time of 100,000 hours although it is still being developed by the task group on VHTR. Another interesting code is Code Case N-499[3] which is for the use of SA508/SA533 steels as the RPV material instead of Mod9Cr-1Mo under limited conditions.

Table 2. Methodology Comparisons Among the Codes

	ASME NH	RCC-MR	Japan (BDS/DDS)	UK R5
Application	General High Temp Structure	LMFBR	LMFBR	General High Temperature
Ratcheting (Shakedown)	O'Donnel Porowski	Efficiency Diagram	Special Rule Including Sodium Level	Residual Stress Field, $f(\sigma_{el} + RSF) \leq K_s\sigma_y$
Inelastic Strain Limits	Neuber Rule and Poisson's Effect (1%,2%,5%)	Neuber Rule, Multiaxial (1%,2%)	Neuber Rule, Elastic Follow-up (1%,2%)	-
Creep-Fatigue Damage	Time Fraction Rule, Envelop Method	Time Fraction Rule, EF, Von Mises	Time Fraction, Elastic Follow-up (EF)	Ductility Exhaustion Method and Elastic Follow-up
Creep-Fatigue Damage Interaction	Bi-Linear Summation Rule	Bi-Linear Summation Rule	Bi-Linear Summation Rule	Linear Summation Rule

ASME ST-LLC has recently been launched as a not-for-profit code and standards commercialization company to develop the technical basis documents that are necessary to update and expand the appropriate materials, construction, and design codes and standards for an application in future Generation IV nuclear reactor systems (VHTR). The following 12 projects are underway sponsored by DOE.

-Verification of allowable stresses
-Regulatory safety issues in structural design criteria for ASME NH
-Improvement of ASME NH rules for negligible creep & creep-fatigue of G91
-Updating of ASME CC N-201
-Creep-fatigue procedures for G91 and Hastelloy XR
-Graphite and ceramic code development
-NH evaluation and simplified methods
-Identification of testing needed to validate ETD procedures for the VHTR
-Environmental and neutron fluence effects
-ASME code rules for IHX
-Flaw assessment and LBB
-Improved NDE methods for metals

3. French RCC-MR Code

The RCC-MR Code[4], intended for the design of LMFBR structures, was issued in 1985 by the collaboration of CEA, EDF, and NOVATOME and has been revised a couple of times so far. The RCC-MR may be applied to the design of a VHTR but the necessary materials are lacking and the range of the application temperatures needs to be extended to a very high temperature as in the ASME-NH. The currently contained materials and the temperature limits are shown in Table 1. The design and analysis procedures are similar to the ASME-NH with several different features described in Table 2. The most conspicuous one is Appendix A16 which is for the high temperature LBB and defect assessments.

4. Japanese Code for VHTR

The JAERI (currently JAEA) developed a high temperature structure design code[5] for the design of the class 1 components of the HTTR based upon the ASME Code Case N-47 and the Japanese BDS[6] Code for the design of the Class 1 components of the MONJU. Table 1 shows the structural materials and the allowable temperatures. HTTR helium environmental effects and the irradiation effects on 2.25Cr-1Mo steel, used as the RPV material, were included. The principal design methodologies are similar to the BDS as shown in Table 2.

5. UK R5 Procedure

Procedure R5[7] contains a structural integrity assessment of the high temperature structures. This is not for a design purpose but for an assessment for both the defect free structures and the defects. Though the R5 code does not provide any material properties since they are the companys' propriety, its assessment methodologies are distinguished from others as shown on Table 2. One of the features is not to consider the interaction effect of a creep-fatigue damage as shown in Fig.1.

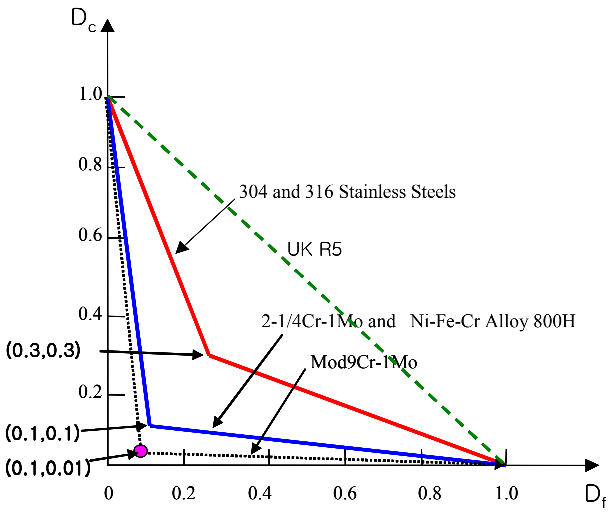

Fig. 1 Creep-Fatigue Damage Interaction Diagram

6. Conclusions and Discussion

The ASME Code, RCC-MR, Japanese Code, and UK R5 were examined. The available materials and the principal methodologies were briefly compared. Even though each code has strong and weak points, these codes are not sufficient for the design and analysis of the VHTR structures at the present time. The presently deficient items in the ASME Code are being developed as described above. The most important thing is to provide additional high temperature materials with proper design data and a vigorous effort is being put into this area in the USA, Europe, Japan, and Korea.

Besides the development of new materials and a design database, a proper design and analysis methodology is necessary for the new material especially at a very high temperature. For example, each country uses a different creep-fatigue damage interaction diagram as shown in Fig.1 and more discussions are needed for the reliability of the method. For Mod9Cr-1Mo steel, UK does not consider the interaction effect and ASME uses a narrow region (0.1,0.01) while RCC-MR uses the same area as 316SS (0.3,0.3). The viscoplastic constitutive equations with reliable material parameters for these materials are necessary since the material behavior may not be adequately simulated by a conventional elasto-plastic-creep analysis. The environmental effects of a helium coolant and the irradiation effects need to be included quantitatively.

Also, the high temperature LBB approach in the frame of the defense-in-depth analyses aimed at demonstrating the robustness of a design is necessary. If existing rules to cope with the VHTRs peculiarities (IHX, Core Support Structures etc) are found not to be suitable, separate design rules need to be supplemented.

ACKNOWLEDGMENT

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