STP-NU-039

CREEP AND CREEP-FATIGUE CRACK GROWTH AT STRUCTURAL DISCONTINUITIES AND WELDS

ASME STANDARDS TECHNOLOGY, LLC

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FOREWORD

This document is the result of work resulting from Cooperative Agreement DE-FC07-05ID14712 between the U.S. Department of Energy (DOE) and ASME Standards Technology, LLC (ASME ST-LLC) for the Generation IV (Gen IV) Reactor Materials Project. The objective of the project is to provide technical information necessary to update and expand appropriate ASME materials, construction and design codes for application in future Gen IV nuclear reactor systems that operate at elevated temperatures. The scope of work is divided into specific areas that are tied to the Generation IV Reactors Integrated Materials Technology Program Plan. This report is the result of work performed under Task 8 titled "Creep and Creep-Fatigue Crack Growth at Structural Discontinuities and Welds."

ASME ST-LLC has introduced the results of the project into the ASME volunteer standards committees developing new code rules for Generation IV nuclear reactors. The project deliverables are expected to become vital references for the committees and serve as important technical bases for new rules. These new rules will be developed under ASME's voluntary consensus process, which requires balance of interest, openness, consensus and due process. Through the course of the project, ASME ST-LLC has involved key stakeholders from industry and government to help ensure that the technical direction of the research supports the anticipated codes and standards needs. This directed approach and early stakeholder involvement is expected to result in consensus building that will ultimately expedite the standards development process as well as commercialization of the technology.

ASME has been involved in nuclear codes and standards since 1956. The Society created Section III of the Boiler and Pressure Vessel Code, which addresses nuclear reactor technology, in 1963. ASME Standards promote safety, reliability and component interchangeability in mechanical systems.

Established in 1880, the American Society of Mechanical Engineers (ASME) is a professional not-for-profit organization with more than 127,000 members promoting the art, science and practice of mechanical and multidisciplinary engineering and allied sciences. ASME develops codes and standards that enhance public safety, and provides lifelong learning and technical exchange opportunities benefiting the engineering and technology community. Visit www.asme.org for more information.

The ASME Standards Technology, LLC (ASME ST-LLC) is a not-for-profit Limited Liability Company, with ASME as the sole member, formed in 2004 to carry out work related to newly commercialized technology. The ASME ST-LLC mission includes meeting the needs of industry and government by providing new standards-related products and services, which advance the application of emerging and newly commercialized science and technology and providing the research and technology development needed to establish and maintain the technical relevance of codes and standards. Visit www.stllc.asme.org for more information.

EXECUTIVE SUMMARY

The subsection ASME NH high temperature design procedure does not admit crack-like defects into the structural components. The US NRC identified the lack of treatment of crack growth within NH as a limitation of the code and thus this effort was undertaken. This effort is broken into two parts. Part I involved examining all high temperature creep-fatigue crack growth codes being used today and from these, the objective was to choose a methodology that is appropriate for possible implementation within NH. The second part of this task is to develop design rules for possible implementation within NH. This second part is a challenge since all codes require step-by-step analysis procedures to be undertaken in order to assess the crack growth and life of the component. Simple rules for design do not exist in any code at present. The codes examined in this effort included R5, RCC-MR (A16), BS 7910, API 579, and ATK (and some lesser known codes).

There are several reasons that the capability for assessing cracks in high temperature nuclear components is desirable. These include:

- Some components that are part of GEN IV reactors may have geometries that have sharp corners – which are essentially cracks. Design of these components within the traditional ASME NH procedure is quite challenging. It is natural to ensure adequate life design by modeling these features as cracks within a creep-fatigue crack growth procedure.
- Workmanship flaws in welds sometimes occur and are accepted in some ASME code sections. It can be convenient to consider these as flaws when making a design life assessment.
- Non-destructive Evaluation (NDE) and inspection methods after fabrication are limited in the size of the crack or flaw that can be detected. It is often convenient to perform a life assessment using a flaw of a size that represents the maximum size that can elude detection.
- Flaws that are observed using in-service detection methods often need to be addressed as plants age. Shutdown inspection intervals can only be designed using creep and creep-fatigue crack growth techniques.
- The use of crack growth procedures can aid in examining the seriousness of creep damage in structural components. How cracks grow can be used to assess margins on components and lead to further safe operation.

After examining the pros and cons of all these methods, the R5 code was chosen as the most up-to-date and validated high temperature creep and creep fatigue code currently used in the world at present. R5 is considered the leader because the code: (i) has well established and validated rules, (ii) has a team of experts continually improving and updating it, (iii) has software that can be used by designers, (iv) extensive validation in many parts with available data from BE resources as well as input from Imperial college's database, and (v) was specifically developed for use in nuclear plants.

R5 was specifically developed for use in gas cooled nuclear reactors which operate in the UK and much of the experience is based on materials and temperatures which are experienced in these reactors. If the next generation advanced reactors to be built in the US use these same materials within the same temperature ranges as these reactors, then R5 may be appropriate for consideration of direct implementation within ASME code NH or Section XI. However, until more verification and validation of these creep/fatigue crack growth rules for the specific materials and temperatures to be used in the GEN IV reactors is complete, ASME should consider delaying this implementation. With this in mind, it is this authors opinion that R5 methods are the best available for code use today.

The focus of this work was to examine the literature for creep and creep-fatigue crack growth procedures that are well established in codes in other countries and choose a procedure to consider implementation into ASME NH. It is very important to recognize that all creep and creep fatigue crack growth procedures that are part of high temperature design codes are related and very similar. This effort made no attempt to develop a new creep-fatigue crack growth predictive methodology. Rather examination of current procedures was the only goal. The uncertainties in the R5 crack growth methods and recommendations for more work are summarized here also.

Finally, it is important to recognize that R5 was developed as an "assessment" procedure. A high temperature assessment procedure is used to assess or determine the effect of cracks on safety and performance of high temperature components. As such, it is not really used for design.